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Proceedings of the Seventh Workshop on Culturally-Aware Tutoring Systems (CATS2024)

Emmanuel G. Blanchard, Isabela Gasparini, Maria Mercedes T. Rodrigo

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7th International Workshop
on Culturally-Aware Tutoring Systems
(CATS2024)

Recife, Brazil
July 8, 2024

In conjunction with the 25th International Conference on
Artificial Intelligence in Education

FOREWORDS

The International Workshop on Culturally-Aware Tutoring Systems (CATS) had been held 6 times to date, in conjunction with ITS and AIED conferences: ITS2008, AIED2009, ITS2010, AIED2013, ITS2014, and AIED2015. It has grown in popularity since its first edition, a trend reflected by an increasing number of submissions, a steady participation of researchers, and the enthusiasm we faced when assembling our program committee for the 2024 edition.

This shows that many researchers in the AIED community clearly see the relevance of this workshop and the importance of having an event to discuss culture and AIED in a transversal way. For many colleagues, it is indeed becoming increasingly crucial to understand and integrate diverse cultural perspectives to ensure that developments, technologies and methods arising from AIED research are inclusive, equitable and globally relevant.

CATS2024 has been designed as a half day hybrid event to help participants (especially newcomers) develop a richer, and more nuanced understanding of the challenges and opportunities of taking culture into account in AIED. With its different sessions with complementary formats and objectives, this event will help AIED researchers deepen their knowledge and understanding of existing CATS initiatives and perspectives. We hope that new ideas will be sparked by these engaging discussions, and that international collaborations will emerge from this event.

We would like to thank the various people who made this new edition of the workshop possible, first and foremost the authors of the 7 selected papers, which you will find in the rest of these proceedings. We would also like to thank the members of the program committee, whose comments helped to improve the various contributions. We also thank the AIED2024 workshop chairs, Cristian Cechinel and Carrie Demmans Epp, the AIED2024 local organizing chairs, Rafael Ferreira Mello and Taciana Pontual, and the student and technical volunteers who greatly facilitated the event. Finally, we would like to thank all the participants: with 94 registered attendees, among which over 50 in-person participants, CATS2024 was the most popular edition of our event series.

*Emmanuel, Isabela, and Maria Mercedes
CATS2024 Chairs.*

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Pre-Literate, Multi-Literate, Post-Literate: Expanding Horizons for LLMs

Jon Mason¹, Carla C. Eisemberg¹, Cat Kutay¹, Sarah Sutcliffe¹, Joanne Forrest¹,
Bev Babbage¹

¹ Charles Darwin University, Darwin NT 0810, AUSTRALIA
Jon.Mason@cdu.edu.au

Abstract. While digital technology (pre-GenAI) has been considered controversial as an enabler for preservation of First Nations cultural knowledge, AI is positioned to unleash new futures in ‘engineering of intelligent human-technology ecosystems that support learning’. For researchers committed to honouring First Nations culture and knowledge, Generative AI (GenAI) now needs to consider how to support a ‘post-literate’ paradigm that weaves in the ‘pre-literate’. As society recognises the existential crises that result from the present consumption, the integration of old ways is crucial in our learning and our practice. The new frontiers of knowledge sharing in AI are looking at oral communication, a tool used at a highly sophisticated level by First Nations. The trajectories of change since the beginnings of the digital revolution demonstrate a broadening of accepted dimensions of literacy. This term is now co-opted in public discourse and appears alongside ‘media’, ‘information’, ‘financial’, ‘digital’, ‘data’, etc. The construct of ‘multi-literacies’ captures this. We consider why it is significant to honour the ‘pre-literate’ for the knowledge they bring, and to support them to engage beyond the multi-literacies of contemporary educational curricula with this post-literate environment. Simply, while much has been lost, it is the resilience of First Nations cultural knowledge that has made it survive. Moreover, there is the issue of first language and the knowledge it encodes. There is already plenty of debate concerning the biases that LLMs embed and lack of support for low resourced languages. What about the bias against first language knowledges? In this paper, we report on the efficacy and evolution of GenAI-assisted teaching and learning at a remote Australian University.

Keywords: GenAI, First Nations, language models, literacies, Indigenous Allyship.

1 Introduction

An enduring assumption in educational curricula worldwide is that literacy and numeracy are the foundations from which all disciplinary knowledge and skills develop. Yet there is plenty of evidence to suggest that this is not universally the case, particularly when Indigenous Knowledge Systems (IKS) are considered. In this article, we explore notions of ‘pre-literate’, ‘multi-literate’, and ‘post-literate’ to frame the limits of contemporary LLMs used to train Generative AI (GenAI). While ‘literate’ is a term with broad utility that indicates an ability to communicate, common usage places emphasis

on the ability to read and write – in other words, to interact meaningfully with text or literature. We use the term ‘pre-literate’ not in any pejorative sense but to bring historical perspective into contemporary discourse on literacy. Secondly, ‘multi-literate’ is introduced as a construct that sits within the evolving digital environment and spans specific kinds of literacy – information literacy, technical literacy, digital literacy, media literacy, data literacy, etc. Arguably, it is a contemporary *de facto* ‘assumption’ about the competencies required to successfully learn with digital technologies. By introducing ‘post-literate’, we wish to signal a paradigm shift triggered by recent developments in GenAI whereby the production of text is increasingly a trivial exercise.

The oral repository of First Nations cultural knowledge, with oral ‘literature’ positioned and threaded through stories, ecological patterns, and navigational cues is an important resource in governance, sustainability, and sophisticated processes. These stories combined knowledge about land, sea, and sky into one narrative, as they may end with the creative ancestors rising to become a star in the sky. This creates an immediate clash of conceptual understandings where these early and continuous living knowledge of patterns over time are often othered and positioned through overlaid colonialist knowledge perspectives. In conceptualising GenAI, the semantics of written literature place emphasis of the role of the fixed text, when Indigenous Knowledge Systems (IKS) span a richness of knowledge and knowing in a much longer arc of time than the scientific paradigm since Galileo. Imagining the in-between spaces of dawn and sunset are both real and conceptual spaces of imagination and innovation where critical GenAI, as an agent in higher education that requires constant critique and inquiry, can expand beyond the one-stop-shop students are now relying on to generate quick renditions of text-based ‘knowledge’. If these agents are to serve First Nations authentically, then the underlying large language models (LLMs) would need to be trained through oral inputs. However, such an undertaking is impossible due to the lack of sufficient data, so how might GenAI tools develop without bias against First Nations languages that have hitherto survived for millennia? Finding answers to this problem are crucial especially in educational contexts where First Nations languages are other than the language of instruction (Knight et al., 2023).

This paper is informed by the reflective practice and scholarship of several teaching academics from diverse disciplinary backgrounds at Charles Darwin University (CDU) in Australia. The common interest that has enabled collaboration for this paper is the potential of GenAI for teaching and learning, specifically in First Nations contexts. Beyond the disruptive impact that raises many issues concerning the very nature of learning, including ethical academic conduct, are the promising ways that co-production of new knowledge might enrich a broader societal (re)-discovery or appreciation of First Nations knowledge and insight, while respecting the holders of this knowledge.

2 Both Way learning

Situated in northern Australia, CDU is uniquely positioned as an institutional catalyst for bridging connections between contemporary interdisciplinary studies (such as STEM-based teaching methodologies, artificial intelligence, environmental science,

linguistics, and the learning sciences) with First Nations culture and knowledges. This we call both way learning and is analogous to the mixing of salt and fresh water in our streams.

Pertinent examples of ways in which CDU makes such connections is in the support for flexible learning through short intensive courses. Among these offerings have been opportunities to learn the fundamentals of local Indigenous languages such as Yolngu Matha and Bininj Kunwok plus the protocols of undertaking research involving Indigenous collaborators. These offerings have benefited from the affordances of the evolving digital environment, though they also demand basic competencies of engaging with technology. Such programs honour First Nations knowledge and leverage digital technologies as a platform to enable this. Thus, as researchers at CDU with a strong interest in the affordances of GenAI as well as its consequent epistemological and ontological ramifications, the prospects of an emerging ‘post-literate’ paradigm signals new opportunities for such connections. By post-literate, we are signalling a societal sensibility that embraces a rich diversity of knowledge curation and transmission that extends beyond the documented confines of written language. We also imagine that the multi-literate requirements of engaging with the contemporary digital environment may even diminish in a post-literate paradigm where oral languages like those of First Nations, predominate.

Whilst Smith’s (1999) seminal work challenges dominant Western¹ colonial paradigms to recognise the need for decolonising Indigenous research, Kimmerer (2013) explores the scientific intersections, through the ‘cultural interface’ that links First Nations and other knowledge systems (Nakata 1998; Nakata & McGinty, 2009; Yunkaporta, 2009). Stepping into the era of GenAI where the snowballing rate of development intensifies, there is a critical crossroad moment – a convergence of ancient wisdom and cutting-edge technology – an opportunity, in the Australian context where inter-cultural learning proliferates. Even with limited language corpus, researchers and language teachers have been investigating what tools can be used for many years to support language reclamation and sharing (Kutay & Green, 2013). This was part of the pre-GenAI enabling for the preservation of First Nations languages and knowledge.

From these initial attempts has developed many aspirational projects that are seen as opportunity for AI and in general Information Technology, to provide resources to First Nations that help to navigate the cultural interface. For instance, in some communities local people are starting to take on managerial jobs, especially in ranger work for caring for country. However, the government demands Key Performance Indicators that are hard to interpret across the interface, and translation from oral reports to written reports can be made easier using tools such as ChatGPT. Providing more plain English material for these models will improve their interoperability.

However, AI continues to replicate the dominant colonial othering paradigms. We have been using existing models developed from LLM and other large Corpus to support other approaches such as tools for oral translations between English and First Nations languages.

¹ We recognise wide adoption of terminology that uses ‘western’ as a way to contrast with pre-colonial paradigms but also recognise its shortcomings in terms of accuracy globally.

How can GenAI move beyond reinforcing hegemony and instead of being a surveillance-based regurgitative tool, become a universally accessible enabler for cultural, language and knowledge communication across real and imagined borders? We hope by providing more material in suitable languages these models can support First Nations engagement with other knowledge systems in their own language. We also consider the perspectives and innovation First Nations can offer for this path with an ability to “survey the field”.

3 Concerns and Challenges

Research has found one of the main perpetrators of systemic inequities to be the predictive algorithms inherent in GenAI design (Shuford, 2024; Stonier et al., 2023). There is also ample evidence of a new colonialism being driven by GenAI (Adams 2021, Mason et al., 2023, Sherlock 2023). Still, little is known about the models that have been generated through machine learning. Even Explainable AI (xAI) and its focus on governance and transparency (Vishwarupe et al., 2022) misses the nuances of cultural perspectives on knowledge, such as Data Sovereignty required by those who collect or access First Nations data. Heaven (2020) called out AI as racist in its predictive policing algorithms in the United States, compounding negative stereotypes based on race and crime. However, some researchers indicate that change is coming that aims to correct such bias (Williamson, Komljenovic, & Gulson, 2024). Nonetheless, this racism is embedded in Australia through the prevailing First Nations disadvantage discourse prioritising and publicising what is not working in these communities.

An understanding of Artificial Intelligence is also becoming a requirement into many workplaces, and it is understandable that many may feel threatened that this is an area they cannot engage in. However, the first step to understanding the opportunity of AI is by using existing models and revealing their parameters for decision making and deficiencies. For many people the existing models have no relevance and may in fact be harmful. We have seen the effect of facial recognition that was built without samples of black faces (Johnson et al., 2022). With the era of big data, we have also witnessed the rise of ‘surveillance capitalism’ driven by multi-national corporate tech (Zuboff, 2018) and its counterpart in China where ‘social capital’ becomes an instrument of surveillance (Cockburn & Cockburn-Wooten, 2022).

However, there may be avenues to adapt existing models to First Nations needs or re-interpret what we have. We know that most of the world languages cannot be supported by large language models, as there is not enough data from these. However, we have been able to extend models like Tacotron 2 and wav2vec to support Australian First Nations languages. This can assist language teachers by providing through the online Application Programming Interface (api), more examples for students to practice in our First Nations language courses. However, this skirts around the bottleneck in translation material which is a significant area where AI could assist First Nations. The translation of cultural metaphors, values and analogies is yet to be achieved.

A further cultural factor to explore is the metaphors that different people use to understand and engage with AI. For instance, the analogy that the machine is

autonomously intelligent. This influences our ability to engage productively with a flawed tool. There is a question whether AI could be useful in First Nations languages for the purpose of being able to use the complex grammar rules to put together an accurate sentence from as an oral version. Also, word order is fluid in many Australian Aboriginal languages, and the meaning can be in layers or how it is said, an interesting challenge for GenAI.

Engagement of First Nations

There are pathways for employment for First Nations, in producing annotated material for generating models and therefore our work is reliant on working with First Nations knowledge holders and language speakers for the input and how to analyse it. There has been expressed often the concern that these models will take away the work of interpreters and language teachers, however these require very human skills, and the distinction needs to be made clear when designing projects to engage First Nations and their knowledge of language.

First Nations in Australia have an interest in, but real concerns about the use of AI working against their cultural values. A postgraduate team at CDU has developed a prototype text to speech system from a Tacotron 2 model for First Nations languages in Australia. The work also included translation from speech to text based on wav2vec model. By training with a comparatively small set of data of aligned oral/text files we were able to provide a model that does speech recognition on the same voice as it was trained on. We are collecting further examples of this language and others to continue to improve the models. However, we are aware these models may never be shared due to concerns over having someone's voice speaking for others and sharing 'knowledge' not from that country, as well as the way the language is de-personalised. This work has raised concerns from those providing the data about the cultural harm that can arise when sharing knowledge out of context.

Whenever there are such conflicts for First Nations around technology, there are often more generic issues behind the problem. For instance, human copiers and now image generators are imitating Aboriginal art and this can be sold as if from the Aboriginal culture, yet lack any link to country or the stories that are the power of this art work. However, we note this way art is being stolen affects all artists now, so is an embodiment of more general concerns.

While non-First Nations perceptions of these issues are different, perhaps First Nations worldviews uncover such issues easier. While many artists are concerned about their ideas being stolen, First Nations see this as more than an issue of loss of copyright, but also a loss of value and knowledge. When we create a new Frankenstein, we should be asking those who have experienced many Frankensteins to assess the perils and imagine the benefits. While much has been lost, it is the resilience of First Nations cultural knowledge that has made it survive as a coherent and strong knowledge system.

Informed engagement

Perhaps the greatest barrier to the promotion of First Nations knowledge, both in general and through large models such as GPT is the lack of presence of First Nations in the material that is used to generate these models. Also, we see a benefit in training our students how to use Chat systems to assist them to write their knowledge in a suitable format for an engineering report or anthropological essay. We envisage that

through such tools a significant barrier to university will be reduced. We have carried out classes that included ChatGPT and GrammarlyGo with students to produce their reports.

When using these systems, the students are trained to record themselves through transcribing tools to collect their initial ideas. These are fed into a chat system then questions asked or more information given to refine the output. The students are encouraged to ensure that their views are represented in this new format.

By providing this pathway for more First Nations to express themselves within the academy we will ensure that more of the knowledge is available in the written format and hence this will be scrapped on the web by these model generators.

4 Collaborations

According to Sherlock (2023), Australian First Nations ways of knowing have the potential to counterbalance the flooding of GenAI technology with a new colonialist output, recognised as unsustainable, but once again with the potential to compound negative stereotypes, instead of contesting the deficit narratives of Australia's First Peoples. Even in terms of the material that is provide by AI models like ChatGPT there is already much misrepresentation of First Nations culture and languages, so it is important to counter this with better information in the mix. This can be achieved while engaging GenAI as a tool for research and teaching.

GenAI can be an assistant to remote First Nations students. Educators and researchers are working with First Nations students, to encode and transmit critical data literacy, ethically and responsibly. One First Nations student highlighted the concept of 'cultural background compass', in the context of navigating Indigenous Allyship (Forrest, 2024), explaining the confusion and conflict between meeting cultural obligations and study obligations in her own words, as she teaches what she feels others need to understand.

It gets really, really hard. Because for example, I'd have my final prac in a month time (teacher education placement). And if I have to get up and leave to go and do something that's important for home where I'm from, then I have to go because I can't put cultural lore on hold for higher ed Western law. I follow my law first as my cultural background compass (Sharona Bishop, Ngarinman Teacher Education Student – PhD Interview Data, (Forrest, 2024 Thesis Unpublished) – with permission by the participant to use full name in this article and for the explicit purpose of this article).

The concept of a 'cultural background compass' (Forrest, 2024), might be imagined as a valuable lens through which to scrutinise and critically assess the information disseminated by GenAI by honouring each person's identity and cultural knowledge, in their own way.

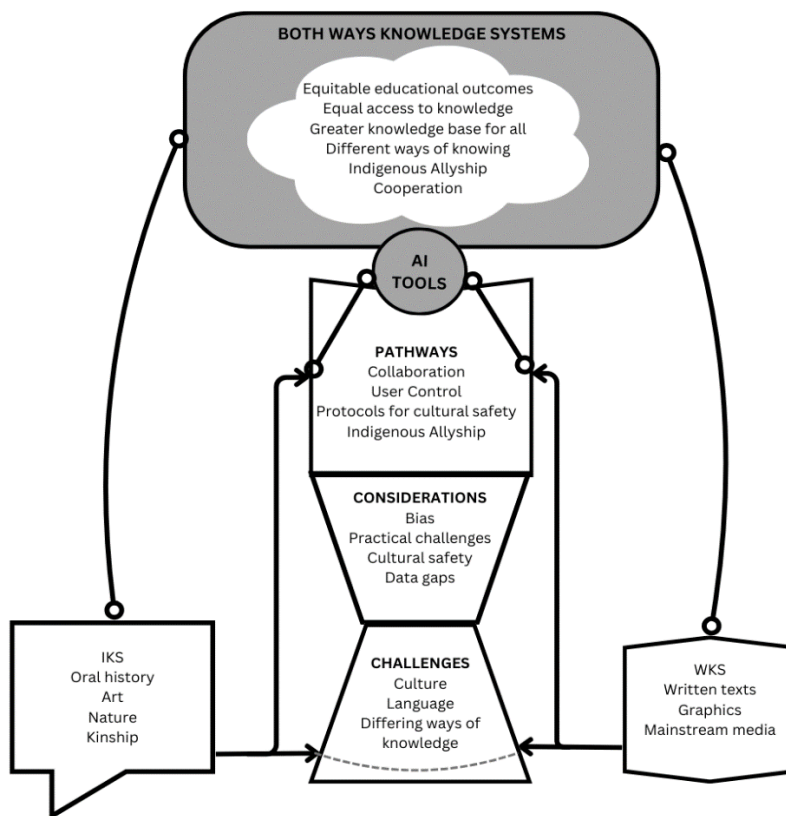


Figure 1. Collaborative pathways which can be potentially utilized to overcome the roadblocks to appropriate design and use of GenAI. The lines on the diagram represent the existing and potential pathways of knowledge exchange/education for both Indigenous Knowledge Systems (IKS) and Western Knowledge Systems (WKS). Through conventional methods, knowledge is miscommunication or ‘lost in translation’ (broken lines).

Paulo Freire’s work on critical consciousness (Freire, 2011) enables us to reimagine GenAI through a culturally relational lens—one that acknowledges agency, social justice, and transformative action. In Freire’s work release from oppression comes from within the oppressed. GenAI can not only optimises algorithms but also respects cultural nuances if trained in these variations across languages. This combination of knowledge from different languages can contribute to the preservation and celebration of diverse worldviews and country where the knowledge is held. GenAI can empower users to engage critically, ensuring that the technology aligns with their values and aspirations.

AI is now positioned to enable ‘engineering of intelligent human-technology eco-systems that support learning’. This is done in a collaboration between technologists,

educators, and First Nations to workshop opportunities for educational settings that may benefit First Nations. These both way learning sessions share perceptions of the technology and the possible values of the exemplars created from the discussion will be shared openly with time to listen to and understand First Nations perspectives.

Expanding on Cooper et al.'s (2024) call for community engagement, data sovereignty and assurance that communities will access the benefits and data in an accessible format at the end of the project, Fig. 1. above represents the existing and potential pathways of knowledge exchange/education between 'separate' knowledge systems. GenAI tools, when acknowledging 'both ways' knowledge systems and taking in consideration LLMs biases, challenges and data safety concerns, has the potential to become a pathway for safe teaching and learning collaboration and allyship. Once collaborative pathways are utilized to overcome the challenges to appropriate design and use of GenAI, the barriers of language (written or otherwise) would be surpassed leading to meaningful both-way connections of knowledge and therefore improved outcomes.

5 Future Work

We take our cues from a growing list of recent constructs that foreground a paradigm shift ... 4IR (Schwab 2017), IoT, Society 5.0 (Fukuyama 2018), blockchain-driven trust-distributed Web 3.0 (Chohan 2022), learning engineering (Goodell, Kolodner & Kessler, 2022) not to mention the Singularity (Kurzweil 2005) to see a future where openness and diversity thrive.

For researchers committed to positioning First Nations culture and knowledge at the forefront of research, GenAI now requires attention to and scrutiny of the 'post-literate' paradigm, and therefore emerging novel relationships and links with the 'pre-literate' where a broader understanding of oral knowledge curation is understood. Just as 'post-human' signals the technological augmentation of human identity, and 'post-digital' emerges as a critical perspective of the pervasive dominance of digital technology and the datafication of social life, the notion of 'post-literate' emerges due to the pervasive bloat of plausibility and clichéd grammars of generative text produced by large language models (Mason, 2023). Furthermore, the direction of post-literate expression is towards recognition of oral communication again, and it is Facebook which has developed the first AI models for oral-to-oral translation²

Acknowledgments. Respectfully, the terminology of First Nations, Indigenous and Aboriginal is used interchangeably throughout the article.

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On Digital Divide within a Developing Country: Investigating Gender and Location Influence in ICT Study Engagement in Cambodia

Dynil Duch^{1,2}, Madeth May¹, Emmanuel G. Blanchard¹, and Sébastien George¹

¹ LIUM, Le Mans Université, 72085 Le Mans, Cedex 9, France

² Institute of Digital Research & Innovation, Cambodia Academy of Digital Technology, Phnom Penh, Cambodia
{dynil.duch.etu, madeth.may, emmanuel.blanchard, sebastien.george}@univ-lemans.fr

Abstract. In Cambodia, as in many parts of the world, access to Information and Communication Technologies (ICT) education is crucial for individual empowerment and national development. However, disparities in access and participation persist, particularly regarding gender and geographical location. Structured into two studies, our research effort investigates these inequalities by analyzing data from the Cambodia Academy of Digital Technology (CADT) entrance exams conducted between 2020 and 2022. Study 1 focuses on gender differences in ICT study engagement, revealing significant disparities in application and success rates among men and women. Study 2 explores location differences in ICT study performance, highlighting the impact of unequal technological development across urban and rural areas. Our findings underscore the urgent need to address these disparities through targeted interventions. Such initiatives could be supported by developing Culturally-Aware Technologies targeting characteristics and challenges within Cambodian society.

Keywords: Digital divide · ICT Education · Gender Disparity · Location Influence · Cambodia · Educational Equity · Higher Education.

1 Introduction

The digital divide, a pressing global issue of unequal access to information and communication technologies (ICT), has been extensively studied [5, 28, 23]. This divide manifests in various forms, such as disparities in internet access [30, 29], digital literacy [9, 27], and the availability of technological resources [7, 6]. For instance, in many developing countries, a significant portion of the population needs reliable internet access, hindering their ability to participate in the digital economy [10, 1]. In contrast, more developed nations enjoy widespread connectivity, facilitating innovation, education, and economic growth. This imbalance

has far-reaching consequences, impacting education, economic opportunities, and social inclusion. The urgency to address this issue is paramount.

One prominent consequence of the digital divide is its effect on education. In regions with limited ICT access, students often miss out on digital learning tools and resources, leading to lower educational outcomes [12, 8]. For example, during the COVID-19 pandemic, the shift to online learning exacerbated educational inequalities, as students without internet access or digital devices could not fully participate in remote education [15, 14]. This issue affects immediate learning and has long-term implications for employment prospects and socioeconomic mobility.

In the field of Artificial Intelligence in Education, the Digital Divide and its consequences have already been discussed on a global scale [24, 4]. In the context of this study, we provide additional insights by investigating possible digital divide within a developing country, Cambodia. We focus on 2 dimensions: gender and localization. Our research question investigates the factors influencing engagement and commitment in ICT studies in Cambodia. By dissecting the interplay between gender and geographical location, we seek to uncover the underlying dynamics shaping access to and participation in ICT education.

Our paper is structured into two distinct yet interconnected studies to address our research question. We begin by examining gender differences in ICT study engagement and investigate location-based disparities in ICT study performance. Each study is preceded by a discussion of our general methodology, with specific details provided for each analysis. We present our findings from both studies, accompanied by preliminary discussions to contextualize the results within the broader landscape of STEM and ICT education disparities.

Our study not only contributes to the existing literature by offering insights into the digital divide within Cambodia but also provides practical implications for the design and implementation of targeted interventions. By comparing our findings to global trends in STEM and ICT education disparities, we underscore the urgency of addressing these issues on a national and international scale. Ultimately, our research aims to advance discussions on educational equity and pave the way for initiatives aimed at bridging the digital divide in Cambodia and beyond.

2 State-of-the-Art

The digital divide, a significant global issue characterized by unequal access to ICT, has far-reaching consequences [1, 12, 2]. Studies have shown this divide is prevalent across various countries, leading to disparities in education, employment, and overall quality of life. For instance, limited access to the internet and digital devices hampers educational opportunities in many developing nations, affecting students' ability to engage with modern learning resources and tools [21].

The digital divide particularly impacts women, who are underrepresented in STEM fields, including ICT [11, 19, 17]. Research indicates that women face

multiple barriers, such as societal norms and gender biases, which discourage their participation in these fields. This underrepresentation is a global issue [16] observed in developed [26] and developing [3, 22] countries. It contributes to the broader gender gap in the technology and engineering sectors [18].

Within this discourse, a research [26] has extensively discussed the unequal distribution of the digital divide among countries and its potential impact on future populations. Their insights highlight the stark differences between wealthy Western countries and the rest of the world, underscoring how access to ICT can influence economic and social development. This disparity not only affects individual opportunities but also has broader implications for national progress and competitiveness in the global market.

Similarly, [4], drawing on research from psychology, has explored similar imbalances within the field of artificial intelligence in education. Their work suggests that psychological factors, including self-efficacy and societal expectations, significantly shape individuals' engagement with ICT.

Efforts to address the digital divide have been varied and multifaceted [20]. Governments, non-governmental organizations, and private sectors have launched initiatives to improve ICT access and education [25]. These efforts include providing affordable internet services, distributing digital devices to underserved communities, and implementing educational programs that promote digital literacy. Additionally, there is a growing emphasis on creating inclusive technologies that cater to diverse user needs, thus fostering a more equitable digital environment [13].

In this context, our research makes a unique contribution by investigating the digital divide within a developing country, with a specific focus on Cambodia. By examining gender and location dimensions, we aim to uncover the factors influencing engagement and commitment in ICT studies. Our study not only offers new insights into the digital divide within Cambodia but also provides practical implications for the design and implementation of targeted interventions. Our research primarily aims to advance discussions on educational equity and pave the way for initiatives to bridge the digital divide in Cambodia and beyond.

3 Method

Our study analyzed data from entrance exams administered by the Cambodia Academy of Digital Technology (CADT) over three years (2020-2022), and personal data used in our analysis were anonymized to ensure confidentiality and compliance with data protection regulations. CADT is a premier institution in Cambodia dedicated to advancing digital technology education and training, playing a crucial role in developing the nation's ICT workforce. Unlike other universities in Cambodia, CADT requires students to pass an entrance exam before they can enroll in a bachelor's program. Before taking the entrance exam, students must choose one of three majors they intend to enroll in, making the entrance exam data particularly valuable for our research.

The initial dataset comprised 7,527 records, including detailed information on applicants' gender, chosen majors, and exam results. Due to incomplete location data, our investigation of geographical factors was based on a subset of 3,650 records.

The entrance exams covered three majors, each representing a critical area within the ICT field:

1. **Computing and Technology:** this major focuses on foundational and advanced computing concepts, including software development, algorithms, data structures, and systems design. Graduates typically pursue careers as software developers, systems analysts, data scientists, and IT consultants.
2. **Telecommunications and Networking:** this field deals with designing, implementing, and managing communication systems and networks. It includes wireless communication, network security, and the Internet of Things (IoT). Career opportunities for graduates include network engineers, telecommunications specialists, and cybersecurity experts.
3. **Digital Business and Management:** this major combines business management principles with digital technologies. It covers areas like e-commerce, digital marketing, and data-driven decision-making. Graduates often work as digital marketing managers, e-commerce strategists, business analysts, and IT project managers.

In addition to analyzing entrance exam data, we conducted a survey using Google Forms with 25 women currently engaged in ICT studies or employment. Based on our analysis results, this survey aimed to gather qualitative insights into their experiences, challenges, and perspectives regarding gender imbalances in the ICT field.

In the following sections, we will examine potential gender-based imbalances in ICT study engagement and investigate whether geographical location contributes to differences in ICT study performance. This approach allows us to understand the factors influencing ICT education participation in Cambodia comprehensively.

4 Study1: Gender Differences in ICT Study Engagement

4.1 Research Hypothesis

Hypothesis 1 posits that there is a gender difference in performance when applying for ICT studies in Cambodia. This hypothesis is based on the global trend that women are underrepresented in STEM fields, including ICT. Various socio-cultural factors, such as traditional gender roles and biases, often discourage women from pursuing careers in these areas. By investigating gender disparities in ICT education, we aim to understand whether similar patterns exist in Cambodia and how they affect women's participation and success in this field.

4.2 Results

Table 1 presents an overview of the gender distribution and success rates among applicants to ICT majors at CADT. This table offers insights into the disparities in ICT study engagement between male and female candidates. It outlines the proportion of applicants by gender across different majors, including Computing and Technology, Digital Management and Business, and Telecommunications and Networking. Additionally, it showcases the success rates of male and female applicants in these majors, providing a comparative analysis of their performance during the entrance exam process. This information sets the stage for a deeper examination of gender differences in ICT study engagement in Cambodia.

Table 1. Application and Success Rates by Major and Gender

Major	Applications (rate)		Success (rate)	
	Men	Women	Men	Women
Computing and Technology	3639 (70.55%)	1519 (29.45%)	2694 (74.03%)	1027 (67.61%)
Telecommunications and Networking	607 (61.69%)	377 (38.31%)	405 (66.72%)	215 (57.03%)
Digital Management and Business	591 (42.67%)	794 (57.33%)	426 (72.08%)	442 (55.67%)

The table 1 shown that men engage more in ICT studies than women in two of the three majors offered at CADT. Specifically, men constitute the majority of applicants in Computing and Technology and Telecommunications and Networking, making up 70.6% and 61.7% of applicants, respectively. In contrast, Digital Management and Business attracts more female applicants, with women comprising 57.3% of the total. However, data from CADT illustrates the underperform of women compared to men in all of the 3 examinations. In Computing and Technology, the data shows that men have significantly higher success rate of 74% compared to 67.6% for women succeeding in this exam. In Telecommunications and Networking, the pattern persists with men achieving a success rate of 66.7%, versus 57% acceptance for women). Finally, the stronger performance gap is observed in Digital Management and Business with 72% of men vs 55.7% of women succeeding in its entrance exam, despite being the sole major where there are actually more women applicants than men.

In order to investigate these results, a total of 25 Cambodian women were contacted, and 16 answered positively (average age 21, SD 4). Responders are from various regions of Cambodia with varying levels of technological development, such as Kandal, Kratie, Kompong Speu, Phnom Penh, Siem Reap, and Banteay Meanchey. All are or have been engaged in ICT studies (9 are current students whereas 7 already have a degree and are working in an ICT-related job). Indeed, targeting women with an ICT-related background was a way to better extract specific characteristics and challenges they may have personally faced or witnessed when engaging in ICT studies.

Many respondents agreed that one of the main explanations for the observed gender imbalances might be cultural and societal norms. For instance, one responder wrote, “Women are less interested in technology majors compared to

men generally. Norm leads us to believe that technology fields are men-dominated and more suitable for men”. Another similarly said, “The way Cambodian parents raise their children, for example, they believe women should be studying accounting, banking majors”.

Another possible explanation provided by many respondents was the lack of early exposure to technology for women compared to men. A Computer Science student from the high development region explained, “Boys tend to receive more encouragement to engage with technology from a young age, giving them an advantage in tech-related skills”. Another respondent from a medium-high development region added, “Men are more likely to play games and get familiar with computers earlier than women”.

A third popular explanation was the perception that ICT majors, except for Digital Management and Business, are too difficult or complex for women. One respondent mentioned, “From my point of view, those two majors preferable for men might involve complex math and calculations, as well as discovering new tech. While studying business is a trend nowadays, women might feel they could manage that without involving any complexities in the field”. And one respond from the low development region said “In fact, most ICT skills for men because this skill is very difficult, sometimes women are weak and cannot master this skill”.

Finally, some respondents highlighted the impact of role models and mentorship. One respondent suggested that the lack of female role models and mentors in ICT fields discourages women from pursuing these majors: “Without visible examples of successful women, young women might be less likely to pursue these majors”.

In summary, the survey results highlight the significant gender disparities in ICT study engagement in Cambodia. Cultural norms, societal expectations, and a lack of role models and mentorship contribute to the lower participation and success rates of women in ICT fields.

5 Study 2: Location Differences in ICT Study Performance

5.1 Research Hypothesis

Hypothesis 2 posits that there exists a location difference in performance when applying for ICT studies in Cambodia. This hypothesis is grounded in the stark disparities in technological development across different country regions. Urban areas benefit from modern infrastructures, including reliable electricity, widespread internet access, and advanced computing facilities. In contrast, many rural areas need more essential technological facilitation, limiting access to ICT resources. Consequently, individuals from urban areas may have greater exposure to technology and more ICT education opportunities than their counterparts in rural regions. This hypothesis seeks to explore the impact of these geographical disparities on ICT study performance and engagement, aiming to shed light on the unequal distribution of educational opportunities within Cambodia.

5.2 Results

Table 2 shows the geographical dynamics of ICT study performance in Cambodia. Our analysis revealed intriguing patterns, pointing out the disparities and challenges faced by students across different regions.

Table 2. Application and Success Rates by Geography Location

Geography Location	Applications (rate)		Success (rate)	
	Number	Percentage	Number	Percentage
High development	1180	32.33%	854	72.37%
Medium-high development	1507	41.29%	1027	68.15%
Medium-low development	850	23.29%	565	66.47%
Low development	113	3.10%	70	61.95%

CADT data included responders from different provinces across Cambodia, including Kandal, Kratie, Kompong Speu, Phnom Penh, Siem Reap, and Banteay Meanchey.

High-development regions emerged as the frontrunners, boasting a substantial influx of applications for ICT majors, and the highest success rates. Following closely behind, medium-high development and medium-low development regions also showed a notable interest in ICT studies and a commendable level of academic performance among students. However, the picture changes as we move to low development regions. Here, we observed fewer applications for ICT majors and comparatively lower success rates.

In other words, candidates from the more technology-savvy regions are the more likely to apply to, and succeed in entering an ICT-related major, which would likely amplify the existing digital divide between Cambodian regions.

These findings underscore the urgent need for targeted interventions and policies to address the unique needs and barriers faced by students in less developed regions. By investing in infrastructure, educational programs, and support systems tailored to the specific challenges of these areas, we can work towards leveling the playing field and ensuring equitable access to ICT education for all students, regardless of their geographical location.

Moreover, these insights have broader implications for Cambodia’s digital development agenda. By addressing the geographical disparities in ICT education, we cannot only provide equal opportunities for all students but also lay the foundation for a more inclusive and digitally empowered society. This, in turn, will lead to a more robust and innovative ICT sector, contributing to the nation’s progress in the digital age.

6 Opportunities for Culturally-Aware Technologies

The findings from our study underscore significant gender and location disparities in ICT study engagement and success rates in Cambodia. Culturally-aware

technologies could help addressing these disparities by providing culturally-specific incentives towards engaging in ICT education. Here, we discuss potential strategies and technological interventions to bridge these gaps.

6.1 Gender-Sensitive Educational Technologies

To tackle the gender imbalance in ICT fields, educational technologies can be designed to focus on inclusivity and gender sensitivity. Examples include:

1. **Role Model Integration:** incorporating stories and case studies of successful women in ICT into educational content can inspire and motivate female students. Virtual mentorship programs and interactive sessions with female ICT professionals can provide guidance and encouragement.
2. **Customized Learning Paths:** adaptive learning platforms that tailor content to individual interests and strengths can help female students find a personalized and engaging entry point into ICT subjects. Highlighting interdisciplinary applications of ICT, such as digital business and management, can make the field more appealing.
3. **Supportive Online Communities:** creating online forums and social networks where female students can connect, share experiences, and support each other can help build a sense of community and reduce feelings of isolation.

6.2 Geographically-Aware Learning Solutions

Addressing location-based disparities requires solutions that consider the varying levels of development and access to resources across different regions:

1. **Mobile Learning Platforms:** given the widespread use of mobile phones, developing mobile-friendly educational platforms can ensure that students from low-development areas can access high-quality ICT education. These platforms can offer offline capabilities to accommodate areas with limited internet connectivity.
2. **Localized Content:** developing educational materials that reflect the local context and language can make ICT education more accessible and relevant to students in different regions. It includes using local examples, case studies, and culturally appropriate teaching methods.
3. **Remote Tutoring and Mentorship:** leveraging videoconferencing and other remote communication technologies, students from underdeveloped regions can receive tutoring and mentorship from experienced educators and professionals. This can help bridge the gap in educational resources and support.

6.3 Inclusive Policy and Infrastructure Development

Beyond technological solutions, policy and infrastructure play a crucial role in addressing these disparities:

1. **Government and Institutional Support:** policies that promote gender equality in education and provide scholarships or financial support for female students and those from underdeveloped regions can encourage more diverse participation in ICT fields.
2. **Enhanced ICT Infrastructure:** investing in developing ICT infrastructure in underdeveloped regions can ensure that students have the necessary tools and resources to pursue ICT education. It includes improving internet connectivity and providing access to computers and other digital devices.
3. **Public Awareness Campaigns:** raising awareness about the importance of gender diversity and regional equity in ICT through public campaigns can help change societal perceptions and encourage more inclusive participation.

By leveraging culturally aware technologies and implementing supportive policies, it is possible to address the gender and location disparities in ICT education in Cambodia. These strategies promote inclusivity and ensure that ICT education's benefits are accessible to all population segments. As Cambodia continues to develop its digital economy, fostering a diverse and inclusive ICT workforce will be essential for sustainable growth and innovation.

7 Limitations

While this study provides valuable insights into the gender and location disparities in ICT education in Cambodia, several limitations must be acknowledged to ensure a comprehensive understanding of the findings and their implications.

1. **Positive Bias Among Female Respondents:** responders of our survey to investigate gender imbalance were all women involved in the ICT domain, either as students or employees. It helped highlighting issues and challenges they may have faced to do such studies but also introduces a potential positive bias, as these respondents are likely to have a more favorable view over ICT than the broader woman population of women. Future studies should similarly investigate barriers and challenges faced by women who chose not to pursue ICT studies.
2. **Incomplete Picture of Degree Completion:** the collected data focuses on entrance exams for ICT-related degrees. However, dropout rates during bachelor programs are not considered. If reasons behind the lack of engagement toward ICT studies also fuel higher dropout rates, this could exacerbate the observed gender and location imbalances, and further widens the digital divide in Cambodian society. Overall, it is crucial to gather and analyze data on how many students, particularly women and those from lower-income regions, complete their degrees, in order to understand the full extent of the digital divide and its implications for the future development of Cambodia's ICT sector.
3. **Need for Comprehensive Data:** comprehensive data on enrollment, retention, and graduation rates by gender and location are needed to fully address the digital divide and its impact on Cambodia's future evolution. By

highlight the importance of having thorough information about the number of students enrolling in ICT programs, the number staying in those programs, and the number of graduates broken down by gender and location. This detailed data helps us understand different groups' specific challenges in ICT education. With this knowledge, we could create targeted programs to support everyone's success. Unfortunately, we do not have all this detailed data, which makes it harder to fully understand the digital divide in Cambodia and how it might affect the country's future.

8 Conclusion

In this study, we explored the gender and location disparities in ICT education in Cambodia, highlighting significant imbalances that may have far-reaching implications for the country's digital future. Our findings align with global patterns of unequal access to ICT, particularly regarding the lower representation of women in STEM fields and the impact of socioeconomic factors on educational opportunities.

The CADT entrance exam data analysis revealed a marked gender imbalance, with men constituting the majority of applicants and successful candidates in Computing and Technology, and Telecommunications and Networking majors. Conversely, women were likelier to apply in the Digital Business and Management major, indicating a preference or perceived suitability for business-oriented ICT fields, but their performance remained lower than men's in this entrance exam as well.

Geographical disparities were also evident. Students from high development regions had higher application and success rates in ICT majors, those from medium-high and medium-low had decent performance in the entry exams, whereas students from low-development regions were by far the least numerous and successful. It highlights the significant impact of socioeconomic status and regional development on access to and success in ICT education.

Our study contributes to the broader discourse on digital equity by providing evidence of internal disparities within a developing country, mirroring global challenges. The observed imbalances highlight the necessity for targeted interventions to address the digital divide in Cambodia. Policies encouraging women's participation in all ICT fields and initiatives to support students from less developed regions are essential. Programs that provide early exposure to technology for girls and promote gender-neutral perceptions of ICT careers have immense potential. They could help balance gender representation and pave the way for a more inclusive future in ICT education. In such a context, Culturally-Aware Tutoring Systems could be key in implementing such programs by providing individualized guidance and support according to cultural norms and challenges.

Furthermore, our study contributes to the existing literature by offering insights into Cambodia's digital divide. It provides practical implications for the design and implementation of targeted interventions. By comparing our findings to global trends in STEM and ICT education disparities, we underscore the ur-

gency of addressing these issues nationally and internationally. Ultimately, our research aims to advance discussions on educational equity and pave the way for initiatives to bridge the digital divide in Cambodia and beyond.

To extend the scope of this research, future endeavors should delve into the development of culturally intelligent features within ICT education. It entails designing curricula, tools, and platforms sensitive to learners' cultural context, thereby fostering inclusivity and engagement. Additionally, exploring innovative pedagogical approaches that cater to diverse learning styles and backgrounds can further enhance the effectiveness of ICT education. Moreover, integrating culturally relevant examples and case studies into the curriculum can facilitate a more profound understanding and relevance for learners from different demographic groups. However, advancing towards a more inclusive digital economy necessitates collaborative efforts across government, educational institutions, and the private sector. By synergizing research and practice, we can develop tailored interventions that address the unique challenges faced by underrepresented groups in ICT education, bridging the digital divide and fostering equitable opportunities for all.

In conclusion, the urgency of addressing gender and location disparities in ICT education cannot be overstated. It is a crucial step towards fostering Cambodia's more equitable and prosperous future. By ensuring that all individuals, regardless of gender or socioeconomic background, have access to quality ICT education, we can empower a diverse workforce capable of driving innovation and growth in the digital age.

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The Influence of Diverse Educational Contexts on Concept Map Structures

Lais P. Van Vossen¹,
Isabela Gasparini¹,
Elaine H. T. Oliveira²,
Berrit Czinczel⁵,
Ute Harms⁵,
Lukas Menzel³,
Sebastian Gombert⁴,
Knut Neumann⁵, and
Hendrik Drachsler^{3,4}

¹ Santa Catarina State University, Joinville, Brazil

² Federal University of Amazonas, Manaus, Brazil

³ Studiumdigitale, Goethe University, Frankfurt, Germany

⁴ DIPF| Leibniz Institute for Research and Information in Education, Frankfurt am
Main, Germany

⁵ IPN| Leibniz Institute for Science and Mathematics Education, Kiel, Germany
{lais.vossen, isagasp}@gmail.com, elaine@icomp.ufam.edu.br,
{czinczel, harms, neumann}@leibniz-ipn.de,
menzel@studiumdigitale.uni-frankfurt.de, {s.gombert, h.drachsler}@dipf.de

Abstract. Concept maps are utilized in diverse educational settings as a means for educators to comprehend students' knowledge construction. However, due to their open nature, the construction of concept maps can vary significantly among students and contexts. We conducted a qualitative assessment of the structure of 317 concept maps from Germany and six from Brazil, encompassing students from secondary to Master's levels, with and without prior knowledge of concept maps, and in both individual and group settings. The maps' structures were classified into network, spoke, or chain, and the German data was used to train a Decision Tree model to classify the map structure. The same model was tested on the Brazilian dataset, the difference in context and culture is one possible explanation for the 19% decrease in models' performance. The paper discusses statistical differences between maps from different contexts and the importance of adapting the teaching and use of concept maps to various educational contexts.

Keywords: Concept map · Decision Tree · Qualitative analysis · Diverse educational contexts

1 Introduction

The field of education generates vast amounts of data [1], which can be used to analyze various educational environments, providing guidance for decision-

making in the observed contexts [2]. One field dedicated to the analysis of such data is Learning Analytics (LA), which emerged approximately 15 years ago and has evolved into a well-established study area for understanding the complexities inherent in teaching and learning across schools and universities [3, 4].

LA stands as a crucial tool for comprehending diverse learning structures, such as Concept Maps (CM), that, according to [5], can be defined as “graphical tools for organizing and representing knowledge. They include concepts, usually enclosed in circles or boxes, and relationships between concepts indicated by a connecting line linking two concepts”. Due to their versatility, they are being utilized in various ways, whether for conducting assessments [6], [7], or even as a study aid that facilitates the observation of knowledge and potential concepts that the student may be struggling to assimilate [8], either way, it is considered a robust test of knowledge and understanding of a topic [14].

The assessment methods for CM are diverse, considering both qualitative and quantitative aspects of their construction [9]. In either form, the analysis of these maps can provide valuable insights into the student’s level of learning, highlighting strengths and knowledge gaps. One of the assessment techniques for concept maps, as proposed by Kinchin et al. [10], involves categorizing them based on their structure and dividing the maps into three distinct categories: network, chain, or spoke. These structures proved to be a robust way [11, 12] for the educator to visualize the different levels of understanding of a given topic by analyzing the concept map structure that the student created [13, 14].

Given the potential of the map’s structure to reveal how students organize their thoughts, the aim of this study is to examine whether this thought pattern can differ across diverse cultures’ characteristics, such as country, educational levels, or individual or group work. Therefore, this study addresses the research question: Can the structural patterns of concept maps learned by a machine learning model be applied to maps from another country or educational context?

To answer this question, we developed a classification model based on the structural data of over 300 concept maps from secondary and high school students in Germany. We then used this model to classify data from undergraduate and postgraduate students in Brazil and compared the characteristics found in each dataset.

The paper is structured as follows. Section 2 presents the concept maps and their structure types. Section 3 introduces the databases used in the paper, how data were prepared and cleaned, and the classification of the CM. Section 4 detailed the Data analysis. Section 5 discusses how we classified the Brazilian data. Section 6 presents the limitations of the research, and section 7 shows the paper’s conclusion.

2 Concept maps and their structure types

The classical concept map was defined by Novak [5] and described as a tool that, when used properly, is simple yet elegantly complex and carries profound meanings. Therefore, the method used to create a concept map is crucial for

achieving its full potential. Thus, Novak presents a pattern for creating concept maps, that begins with a declarative question, such as “What is a concept map?”, followed by the establishment of a bank of ideas and concepts used to answer this question. Subsequently, these concepts should be rearranged hierarchically, and connected by unidirectional edges characterized by simple phrases such as “requires”, “works with”, “leads to”, “involves”, and so forth.

The need to establish standards for evaluating these concept maps has arisen. Different evaluation approaches emerged, including quantitative, holistic, similarity-based on a model concept map, or qualitative ones [16]. Among these evaluation methods, Kinchin et al. [10] proposed categorizing concept map structures into three types: spoke, network, and chain, as illustrated in Figure 1.

An example of a spoke-type map is depicted in Figure 1 in panel A. This type of map exhibits a circular structure wherein all the related aspects of the topic are directly linked to the core concept but not directly connected. Such a structure often indicates superficial and underdeveloped knowledge of a subject. Although new knowledge can be more easily integrated, it may only be accessible through reference to the core concept [14, 10]. In the same figure, panel B illustrates a chain-type map. These structures lack linkage between nodes in different hierarchies and tend to move through available information from start to finish quickly. Consequently, understanding concepts in the middle of the sequence without starting from the beginning may be challenging for students. Additionally, incorporating new knowledge, especially if it disrupts an established sequence, can be difficult [14, 10]. Finally, panel C exemplifies a network-type map, distinguished by its robust and adaptable cognitive typology. This structure enables the comprehension of a diverse range of concepts through different but related routes of thought, demonstrating students’ flexibility in understanding the concept beyond a connection to a core concept or following a specific line of thought [14, 10].

As educational methods become increasingly digitalized, various platforms have emerged that facilitate the creation of digital concept maps. These platforms provide greater spatial flexibility and tools, while also facilitating synchronous and digital collaboration among students to create concept maps. Among these tools, the one used in this work is Hyperchalk, as it functions as a digital and collaborative whiteboard that enables students to use various tools to construct structures, such as concept maps and other types of diagrams, collaboratively. Its open-source nature facilitates local installation and management, while its focus on Learning Analytics (LA) facilitates data collection and analysis [18].

3 Databases

Two databases were used in this study. The first was obtained in collaboration with the Leibniz Institutes DIPF and the IPN, which collected this data using a custom-made digital concept mapping tool with upper secondary biology classes in the federal state of Schleswig-Holstein, Germany. The concept maps were

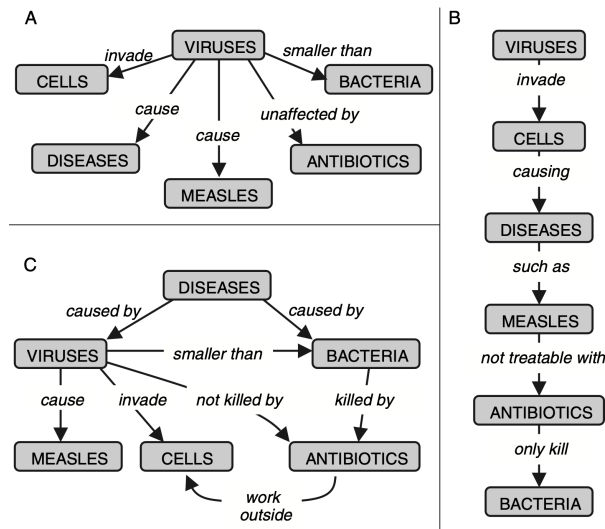


Fig. 1. Examples of concept maps in three structures: A) spoke; B) chain; C) network
Source: Kinchin et al. (2005) [11]

created as part of a concept mapping crash course, which was implemented at the beginning of a ten-week teaching unit on five factors of evolution [19]. The first concept map (i) was created in pairs as an exercise, which tasked students with creating a concept map on the system “school”. The second concept map (ii) was made individually by students at the end of the concept mapping crash course, where students were asked to create a concept map on evolution based on their previous knowledge of the topic. To preserve the anonymity of the students who developed these maps, the available information lacks any user identification, including demographic information such as gender, age, or ethnicity; this could potentially lead to unbalanced data between different populations and affect the data analysis. This dataset comprises 317 distinct maps with at least two links between concepts and, therefore, at least three concepts. The maps are divided into two categories: concept maps about the system “school” and concept maps about evolution.

The second database contains data generated from the use of Hyperchalk for the development of concept maps in the Human-Computer Interaction (HCI) course of the Bachelor’s in Computer Science and the Instructional Design in Practice course of the Master’s in Science, Mathematics, and Technology Education, both at UDESC University in Brazil. This database contains six maps constructed by groups of up to four master’s students and four maps constructed by groups of up to five bachelor’s students. Before the development of the CM, the Master’s students received a class on concept map fundamentals, where they were taught how to construct them and the difference between the three struc-

ture types, and the undergraduates did not receive any instruction about CM. Table 2 summarizes the characteristics of the datasets used in this research.

Table 1. Dataset characteristics

	Secondary Schools	Bachelor's degree	Master's degree
Country	Germany	Brazil	Brazil
Previously learned about concept maps	Yes	No	Yes
Number of concept maps	317	4	6
Type of work	Paired and Individual	Paired	Paired (4) and Individual (2)

3.1 Data preparation and cleaning

Both datasets underwent a transformation process to turn the nodes and edges connections into a directed graph structure, allowing the extraction of statistics data about the number of connections that node had. There was also a feature engineering procedure whereby each map was compiled within a single row of the dataset containing the following information:

- Map identification: the file name that contained the entire concept map;
- Number of nodes: the sum of all nodes in the concept map;
- Number of edges: the sum of all edges in the concept map;
- Number of edges with labels: the sum of all edges that had a valid label in it;
- Mean size of node labels: the average number of words per node label;
- Mean size of edge labels: the average number of words per edge label;
- Ratio between nodes and edges: calculated by dividing the number of edges by the number of nodes in that map. This variable indicates the overall connectivity of a concept map;
- Ratio between nodes and edges with labels: calculated by dividing the number of edges with a label by the number of nodes in that map. This variable indicates the overall connectivity of a concept map but considers only those connections with a label on the edge;
- Mean number of edges per node: the mean number of edges that the nodes have, it represents the mean number of connections by node;
- Standard deviation of edges per node: the expected variation from the mean number of connections by node;
- First quartile: the number of connections a node has, below which 25% of the smallest number of connections by node lie;
- Second quartile: the number of connections a node has, below which 50% of the smallest number of connections by node lie;

- Third quartile: the number of connections a node has, below which 75% of the smallest number of connections by node lie;
- Maximum number of edges per node: the maximum number of edges connected to a node that happens in the concept map.

3.2 Classification among structures types

After transforming the data into graph structures, each map was plotted as a directed graph using the iGraph library [15], omitting all labels and thus retaining only the general format of the map, for that reason, the maps' topic didn't influence the classification. Each image was analyzed and classified as a spoke, chain, or network. To accomplish this, one researcher visually inspected each CM and classified it based on the most predominant structure, similarly to what was done in [11]. Some examples of distinct structures for each of the classes can be seen in Figures 2, 3, and 4.

Figure 2 presents three examples of cases considered as spoke-type structures, with the middle one being the most traditional. The images on the right and left exhibit the main characteristic of spoke structures, featuring key concepts to which various other concepts are connected. However, unlike the traditional image, they have more than one key concept. Similar to the traditional structure, the concepts linked to a key concept lack interconnections among themselves.

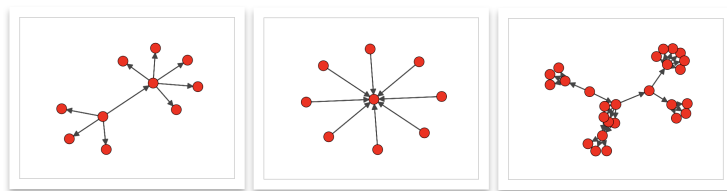


Fig. 2. Examples of spoke structures

Figure 3 presents some examples of structures considered chains, with the middle one being the closest to the classic chain structure. The figures on the right and left exhibit the same pattern of having a node connected to the others through a single chain connection. Although these structures deviate from the classic one by having nodes with more ramifications, these nodes are few, and the main characteristic of the lack of connection between concepts at different hierarchical levels is maintained.

Finally, Figure 4 presents examples of network structures, where highly connected nodes prevail in all cases, without a well-defined hierarchical structure. In the dataset, there are several examples of networks with varying degrees of connectivity, and structures that do not exhibit a prevalence of chain or spoke characteristics were considered as networks.

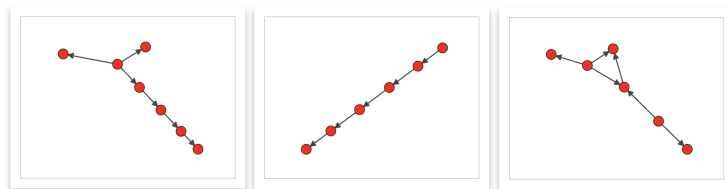


Fig. 3. Examples of chain structures

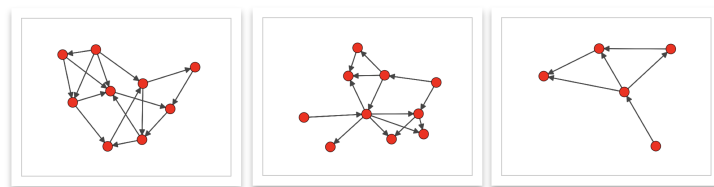


Fig. 4. Examples of network structures

For the German dataset, 61 CM were classified as chains, 191 as networks, and 65 as spokes. For the Brazilian dataset, four CM were classified as networks and two as spokes for Master’s students, and for undergraduates, there were two networks and two spokes. With over 300 CM, there was an extensive range of designs, with some exhibiting a subtle distinction between chain, spoke, or network. Consequently, a potential bias of this work lies in the classification of the concept maps, as there is no set of rules to define each structure clearly. Therefore, the classification is open to interpretation.

4 Data analysis

With the data cleaned for each map, some analyses were conducted to identify differences between the observed features for each educational context. Therefore, Table 2 presents the average values of vertices, edges, and labeled edges across the three observed contexts. On average, master’s students constructed maps with more nodes and edges than undergraduate and K12 education students. However, the map with the highest number of edges was found in the undergraduate group, which could directly affect the high standard deviation number found in this group for the number of vertices. Overall, the analysis of these data shows that as the educational level increases, the number of vertices and edges in the maps also increases. However, without proper instruction, undergraduates had lower averages than K12 education students in the aspect of labeled edges, highlighting the necessity for a detailed explanation of concept maps for students to benefit from this tool fully.

Finally, Table 3 presents the condensed values of the relationships between vertices and edges for the three education levels. The data indicates that al-

Table 2. Data about the number of edges and nodes for all datasets

Dataset	Bachelor's degree	Master's degree	Secondary and High Schools
Mean number of nodes	44.25	58.83	12.76
Mean number of edges	53.75	64.17	10.42
Mean number of edges with labels	2.25	29.67	10.21
Lowest and biggest values for nodes	(21, 93)	(29, 87)	(3, 29)
Lowest and biggest values for edges	(34, 102)	(26, 123)	(3, 28)
Lowest and biggest values for edges with labels	(0, 9)	(0, 52)	(1, 28)
Standard Deviation for number of nodes	33.08	20.28	5.51
Standard Deviation for number of edges	32.48	33.82	5.27
Standard Deviation for number of edges with labels	4.50	24.07	5.41

Table 3. Data about the ratio between nodes and edge for all datasets

Dataset	Bachelor's degree	Master's degree	Secondary and High Schools
Mean ratio between nodes and edges	1.31	1.09	0.81
Mean ratio between nodes and edges with labels	0.02	0.47	0.79
Lowest and biggest values for ratio between nodes and edges	(1.19, 1.62)	(0.56, 1.68)	(0.23, 1)
Lowest and biggest values for ratio between nodes and edges with labels	(0, 0.1)	(0.077, 1)	(0, 1)
Standard Deviation for ratio between nodes and edges	0.22	0.40	0.15
Standard Deviation for ratio between nodes and edges with labels	0.048	0.40	0.17

though the maps of master's students possessed the highest average number of vertices and edges, it was the undergraduate concept maps that exhibited the highest average connectivity rate between vertices, with more edges per vertex than the other maps. However, when considering only the labeled edges, the undergraduates had much lower values compared to those of upper-secondary education and master's students.

5 Classifying Brazilian data

A Machine Learning model was trained to check if the same structural patterns of concept maps made by German upper-secondary students appear in Brazilian concept maps from different contexts. To address this, the German dataset was divided into two parts and balanced to have 100 random samples of each class, with repetition of some chain and spoke structured maps, with 20% of the data used as a validation dataset and the remainder used for model training. Subse-

quently, five multiclass classification models were selected, as presented in Table 4. The models were implemented using the Scikit-learn library [17], with the default settings for each model. Then, the accuracy was evaluated for each model using cross-validation with the default 5-fold cross-validation method, as well as the F1-Score for each class. Table 4 shows that the Decision Tree model outperforms or matches all the metrics, making it the best choice for this particular case.

Table 4. Model results for classification in chain, spoke or network structure

Classifier Model	Accuracy	F1-Score Chain	F1-Score Network	F1-Score Spoke
Decision Tree	0.86	0.96	0.83	0.93
Random Forest	0.86	0.94	0.79	0.93
Logistic Regression	0.78	0.86	0.69	0.77
K Neighbors	0.80	0.78	0.62	0.76
Gradient Boosting	0.86	0.96	0.80	0.91

For a more detailed analysis of the metrics of the selected model, Decision Tree, Figure 5 presents the confusion matrix of the model for each type of structure, as well as the five most important features for prediction, considering the Permutation Importance test, with both of these functions implemented by the Scikit-learn library [17]. In the figure, it's possible to identify that the standard deviation and mean number of edges connected to each node are the most significant in predicting the structure, more than the number of nodes or edges per se.

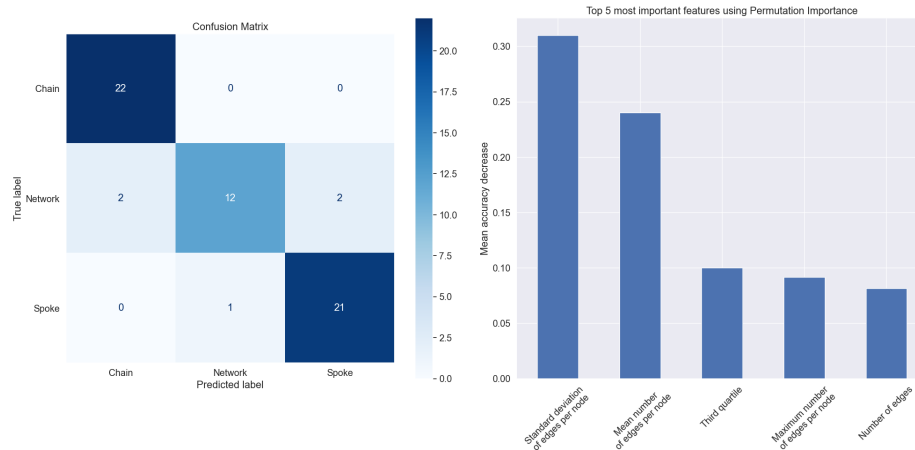


Fig. 5. Metrics for the Decision Tree model trained

The trained model was used to predict the structure of the Brazilian concept maps. The prediction results are shown in Figure 6, where it is evident that for the master’s students’ data, the model misclassified one out of the six maps, resulting in an accuracy of 83%. For the undergraduates’ data, the model misclassified two out of the four maps, resulting in an accuracy of 50%. The overall accuracy of the model was 70% when considering both contexts. This indicates that the model’s accuracy decreased by 19% when compared to the test data from the German dataset. Although the decrease was relatively small, it suggests a pattern change between maps from different contexts. The model trained on data from late secondary education students was not as successful for higher education students.

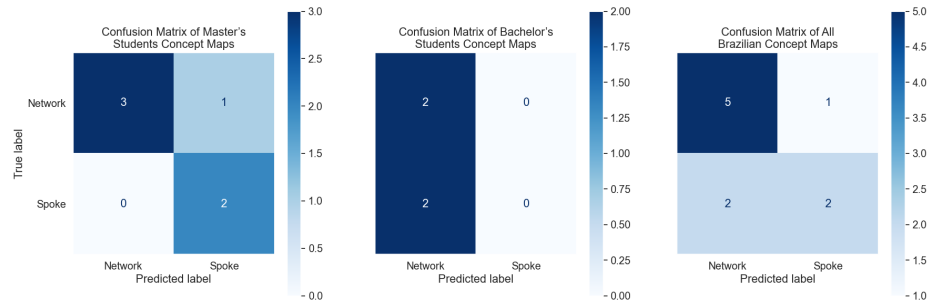


Fig. 6. Confusion Matrix for predicting concept maps structure type in Brazilian datasets

6 Limitations and bias

Some limitations and threats to the validity of the work in this research need to be addressed. The first is related to the size of the Brazilian dataset, which consists of ten concept maps. Despite the limited amount of data, the experiments conducted still allow for a meaningful discussion despite the small number of maps in the Brazilian context.

Another limitation of this research is that the contexts of the two datasets differ in many factors. There is a shift from the German concept maps, which were only partially created in collaboration, to the completely collaboratively or cooperatively created maps in the Brazilian context. Additionally, the educational context differs, with the German dataset consisting of upper secondary school students, while the Brazilian dataset consists of higher education students. In contrast, the Master’s students were taught about it before the map construction process.

These factors make it hard to say how location and culture affect the creation patterns of concept map structures. However, it is understood that given there is

a change in this pattern, future research can isolate these variables to understand what actually influenced this change.

7 Conclusion

The present study quantitatively examined the various elements that make up a concept map, examining a sample of 317 maps made by German students and ten maps made by Brazilian students. The analysis of concept maps across different educational levels reveals significant variations in the construction and complexity of the maps. It was found that Master's students, on average, created bigger maps with more nodes and edges compared to their undergraduate and K12 education counterparts. Furthermore, the data showed that undergraduates without proper instruction in concept mapping had lower average labelled edges than students from late secondary school who received instruction on the topic.

Next, the German dataset was used for training a Machine Learning model for structure classification of the Brazilian concept maps, and this process was used to answer the research question: *Can the structural patterns of concept maps learned by a machine learning model be applied to maps from another country or educational context?*. The model selected was a Decision Tree with 86% accuracy in classifying the German data, and an overall accuracy of 70% with the Brazilian concept maps. This result indicates a change in the construction pattern of concept maps from one context to another, which emphasizes the importance of tailored instruction to enhance students' understanding and utilization of concept maps in all educational stages. Additionally, the construction of a Machine Learning model that allows the classification of the structure of concept maps could provide real-time feedback to students regarding the structure of their maps, guiding learning toward further depth, and helping educators with the assessment of these maps.

As a recommendation for future research, it is suggested to isolate the variables analyzed in this study to explore further how culture characteristics such as country, education level, group or individual work, and previous knowledge of concept maps could affect its structure. In order to mitigate biases in the classification of maps into structures, further research would involve applying a more structured pipeline to define these classifications. This would include defining more robust metrics than visual inspection and involving more researchers in the classification process to analyze the degree of agreement between them by applying the Kappa test [20].

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On the Specification of the Relevant Mathematical Notations

Paul Libbrecht^[0000–0003–3176–3361]

IU International University of Applied Science, Erfurt, DE paul.libbrecht@iu.org

Abstract. Mathematical notations are a form of graphical language used to express statements. The language is thought of as formally well defined and is made of a broad spectrum of symbols. Because of its formality, it is common to consider that mathematical notations (or the mathematical knowledge) are universal and can be universally understood. This consideration is not correct. We describe examples of notations which fail to be universal and propose explanations for these failures. Thus, the following question is natural: How or who should specify the relevant mathematical notations when planning a content or software project? We propose approaches to answer this.

The breadth of the spectrum of mathematical symbols, and the dominating handwritten practice, brings another important aspect to this question: Every mathematician considers himself or herself empowered to create new notations. We explain why this freedom of invention is important and sketch implications for the design of educational tools.

Keywords: Notations · Mathematics · Language · Cultures · Invention

1 Motivation

Mathematics is a branch of science that makes it possible to operate deductions, which include calculations, so as to conclude statements from other statements. Based on a very small set of axioms and the strict application of logics, mathematics has become the central tool to model reality in most applied sciences. Applied sciences are becoming broader every single day and are touching every day lives more and more. As a result the need for every human to master mathematics grows.

Mastering mathematics means to have learned it. In turn, learning mathematics involves not only mastering the knowledge but being able to perform new deductions and apply them. The deduction steps are, nowadays, performed mostly using the symbolic language of mathematical notations which is learned together with the concepts.

Mathematical deductions or models are exchanged via communicative acts: lectures, papers, emails, blogs, social networks... The persons participating to the communicative act all should understand the mathematical notation used if they want to fully understand what is being told. Thus it is natural to study the set of mathematical notations within the environment of a communicative act.

Learning systems are examples of such environments: through a user-interface, the learning system uses mathematical notations and requests them to be manipulated or input by the learner; thus mathematical notations are a central ingredient of these learning systems.

When one considers the very classical environment of a mathematics classroom, the flow of information is mostly well defined: Teachers are responsible for the content being viewed, presented or written, for the use of notations, for the concepts being learned and he or she knows that it is doable to do that in a way that the students will learn.

The more scattered learning situations met in the research activities or in advanced mathematics learning, for example when reading the documentations of statistical software, are examples of environments which must establish a set of notations and possibly need to explain it. This is probably the reason why ISO-8000 [1] has emerged as a description of “the norm” of notations. However, the content of such a standard is not how mathematics is being learned: many persons who visit such environments will likely have to adapt the notations they have learned to the notations being used; this may be cognitively demanding and thus may slow down the reading.

Because learning software needs to teach mathematics to students “where they are”, we ask the natural question: How to decide and specify the set of notations for mathematics learning software?

2 Definitions

We describe as mathematical notations the set of graphical constructs used to describe concepts of the mathematical science using other means than words. In general notation is written in horizontal lines (from left to right or right to left) with the addition of vertical layout constructs. Sometimes complex graphical systems are built with mathematical notations. In many cases, mathematical notation is expressed together with sentences and replaces, grammatically, a word or a clause. This makes it possible to read them aloud.

Mathematical notations are made of symbols, which represent a construct of a well-known semantic. For example an operation (e.g. the and operation of two predicates as in $S \wedge T$), a digit (e.g. the number 7), a decoration (e.g. the bar on top of a statistical sample denoting its average value as in \bar{M}). Each of these notations are examples of ambiguous notations: They only have a meaning if the context is clear (e.g. \wedge could also mean an alternate product of differential forms, the number 7 does not indicate if it is a natural number of a number modulo 5, \bar{M} could also be the complement of the set M).

Each symbol comes with a set of rules to compose it in a meaningful way for example the intersection can be taken between two sets; but intersecting functions or numbers makes little sense to most persons.

The idea of mathematical notation does not define how they are understood. It is the role of an explanation of the notation to do this and to explain the rules

of composition. These rules are often coupled with further reasoning that mirror the properties of the concept in visual effects observed on the notations.

It is common practice to represent the structure of mathematical notation as a tree, where one would see operators applied at the root of a branch and their operands as their children. This representation helps approach a machine based semantic of the mathematical operation as is done in MathML-content [9, chap. 4] or [7]. This bridge to the semantic representation of formulæ is an aspect that can empower learning, computing, and communication systems and support the generation of multiple notations from the same tree. We shall only speak little about this representation preferring to focus on the notations aspect.

3 Rationales behind Mathematical Notations

For a person speaking and reading, at least with a Western language, mathematical notation is an intuitive way to represent mathematical concepts. Compare the following expression in words “the derivative of the product of two functions is the sum of the product of the first function, derived, times the second, and the product of the first function times the second, derived.” with “ $(f \cdot g)' = f' \cdot g + f \cdot g'$ ”. It is rather natural to use the second expression and, at most, hear the first. Two other cases of strongly different expressions are in figure 1.

Thus, mathematical notations has a compression and memory effect. However, this memory effect is only working if the rules that one knows are satisfied. Indeed, an experiment [16] where participants were requested to remember parts of the formulæ showed a clearly stronger ability to remember the formulæ that were well formed compared to those that did not match the well known structure.

Mathematical notations is explained in [20] to have been fuelling the science and understanding of further mathematics: Among the most important notations of human history is the ability to operate and think with numbers. This ability is largely fed by the notations of numbers: It is the central carrier to perform operations such as long additions, subtractions, multiplications or divisions. The evolution has, however, led to diverging notations for each culture.

The decimal representation of numbers is one of the simplest diverging notations: 1.732 can be understood as an integer between one and two thousands (e.g. when articulating a number of Euros in French) or an approximation of the

Boyle’s Law: The absolute pressure exerted by a given mass of an ideal gas is inversely proportional to the volume it occupies if the temperature and amount of gas remain unchanged within a closed system.

$$P \propto \frac{1}{V}$$

Pythagoras Theorem: the area of the square whose side is the hypotenuse is equal to the sum of the areas of the squares on the other two sides

$$a^2 + b^2 = c^2$$

Fig. 1. Two statements expressed in words or in symbols

square root of three (e.g. in the English language). While this difference seems easy to compensate by providing external context, encountering such characters somewhere random on the web may prevent an immediate understanding as extra information is needed.

The expression of mathematical notations has been chosen for its diagrammatic expressivity. As an example, the horizontal alignment, one after the other, of the terms of an operation allows to represent the application of the associativity property (as in $f \circ (g \circ h) = (f \circ g) \circ h = f \circ g \circ h$). Similarly, when on both sides of an equal sign, additions can be visually transported by “taking them on the other side” (changing their sign). This kind of operation is, likely, reminiscent of the geometric addition of lengths when connecting several segments behind each other. Characteristics of the operation such as the ability to move terms (move them around, to the other side of the equality...) are learned when the operations and their notations are learned. Many of the properties can be expressed in a way that corresponds to a move that is recognizable.

We call “haptics of notations”, the connection between the graphic configuration of notations and the moves that are possible. They are an integral part of the understanding of the concepts and of the notations. As far as the author can tell, the movements of the mathematical notations are mostly learned simultaneously as the concepts themselves. An easily remembered example is the distributivity property in figure 2

The effects of allowing manipulations to support learning of mathematics are numerous. The subject of “manipulatives” is a rich object of software and didactical developments. It goes as far as “embedded cognition” described, for example, in this paper [24]; some of the effects include a better memorization.

Manipulations allowed by mathematical notations are helping mathematical habits of mind which are described as differentiating the experienced mathematicians from the less experienced ones [6].

To conclude, we cite the motivating introduction to algebra presented in [13], which shows well the intimate relationship between manipulations and understanding: “Performing calculations with them and using the results to make predictions requires an understanding of relationships among numbers. In this chapter, we will review sets of numbers and properties of operations used to manipulate them.”

This property combines both addition and multiplication (and is the only property to do so).

$$\begin{aligned}
 4 \cdot [12 + (-7)] &= 4 \cdot 12 + 4 \cdot (-7) \\
 &= 48 + (-28) \\
 &= 20
 \end{aligned}$$

Note that 4 is outside the grouping symbols, so we distribute the 4 by multiplying it by adding the products.

To be more precise when describing this property, we say that multiplication distributes true, as we can see in this example.

$$\begin{aligned}
 6 + (3 \cdot 5) &\stackrel{?}{=} (6 + 3) \cdot (6 + 5) \\
 6 + (15) &\stackrel{?}{=} (9) \cdot (11) \\
 21 &\neq 99
 \end{aligned}$$

A special case of the distributive property occurs when a sum of terms is subtracted.

late numbers. This understanding will serve as prerequisite knowledge throughout our study of algebra and trigonometry.”

4 Where do Notations Live

Having described the rich aspects of knowledge that are connected to mathematical notations, we now try to describe the learning processes of mathematics where notations are learned typically along the lives.

First concepts of mathematics appear with fingers and rhythms and in geometry from the age of 2. The surroundings of the children are essential in their structuring of this understanding process.

Mathematical notations start to be learned with numbers. First till 10 or 20 (first years primary), then bigger. The first differences across the cultures start to appear already here: E.g. in Germany, the first two years only show the children numbers till 20 whereas in France, the numbers till 100 appear almost in the first year. Written operations start from 9 or so, unknown and polynomials about at the age of 14 and proofs start to be explicit at the age of 15. But divergences have already started then.

A very visible variation between cultures appear in the 17 different ways of performing the long division as reported in MathML-long-division [9, Section 3.6.8.3].

Multiple other smaller differences occur, in particular those fueled by the language changes. For example, the greater common divisor is written using the first letters of the words in each language (ggT in German, gcd in English¹) or even some other influence (in French, it can be used as pgcd or pgdc depending on the modernity claims of the authors).

Mathematical practice is, itself, influenced by the cultures: When in France a proof can never be summarised in a picture (and is, instead, based on a formal argumentation chain expected in words or symbols); in Germany a proof is often best explained using a picture [17]. Mathematics is tightly bound to the possibilities of languages as explained in this citation: “we bring mathematics into existence by talking about it, and the way we talk about it changes the questions we can ask” ([5] cited in [12] which goes deeper in the affordance of understanding mathematical concepts based on grammatical differences).

Moreover, it should be noted that mathematical understanding and mathematical notations can be influenced by the semantic fields induced by the surrounding languages. For example the concept of “Takt” in German means the physical notion of frequency but it also means the unit of measure of music notations, it may also mean the empathic behaviour of a person. No word exists with these three meanings in French or English (for example) thus the memory of mathematical concept may be connected to different memories depending on the language of the learning.

¹ See <http://notations.hoplahup.net/Census/CD-arith1/gcd> for more notations of the greatest common divisor. This website contains multiple other notation divergences examples.

The impact of cultures on mathematics learning and operating has been so deep that an entire research movement has emerged called *ethnomathematics* which aims at reinventing mathematics having acknowledged the very deep role of cultures, both methodologically and conceptually. An example of reflections is presented in [3].

Based on these early divergences, mathematical notations becomes scattered to a point that ambiguity can, sometimes, only be solved by long investigations. Ambiguities such as the following exist:

- The tradition of using red color to denote negative numbers and green for positive ones (in Western cultures) is inverted in Japan.² A misinterpretation may be the basis of important business decisions.
- Ambiguities include the use of the vertical bar to mean absolute value of a real number, the determinant of a matrix, the cardinality of a set, the such-that construct of sets, or the conditional probability. They imply, for example, that systems that read aloud may encode heuristics such as: $|M|$ is a determinant but $|a|$ is an absolute value (depending on the case of the argument).
- The meaning of $(-100, 100)$ in a course of differential calculus in English for a reader that has not read the course start to end will not be clear: It can be interpreted as the coordinates of a point ($x = -100, y = 100$) or an open-interval of the numbers between -100 and 100 not included.

This section has shown us that aspects of the environment around mathematical notations in a communication act allow a person to “enact” many possible semantic behind mathematical notations when it is not provided with a complete context.

As a way to make sure that the possibly new mathematical notations introduced in a book are clear, it has been common for mathematical texts to include a list of notations at the end of their works. Such a table of notations is presented in figure 3.

5 Inventions of Notations

In his activities with various authors of mathematical texts, the author constantly met the freedom of mathematicians that inventing notations is a “fundamental right”: It should be normal for any creator of mathematical documents to be able to explain enough so that readers can be endowed with new notations.

While it seems presumptuous to express this as a fundamental right, it should be noted that history has repeatedly seen the invention of new notations: The detailed explanations of the symbols’ evolutions of [20] demonstrate this well as the invention of symbols has made it possible to understand new concepts such as arithmetic operations or the mere number 0. Another evidence stems from

² This can be seen in the first web pages of the Tokyo and New York stock-exchanges: <https://www.jpx.co.jp/english/> and <https://www.nyse.com/trading-data> .

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Fig. 3. The list of notations at the end of a book on geometry in French [11].

the notorious reference of F. Cajori [8], recognized as the most complete history of mathematical notations: It contains words such *invent* at least once every 5 pages.

As is the case with just any concept, its relevance only occurs when it is adopted by others and becomes a reproduced *habit of mind* [6]. This can explain why the invention of notation is rarely celebrated as an important action while the concept is more often attributed. Some notations carry their inventor's name (e.g. the derivative notation of Leibniz or Newton, the δ of Kronecker or even the Einstein convention).

The need to invent mathematical notations may be doubted of. After all, the body of knowledge of mathematics is rich and mature. However the will to understand even more mathematics is steadily growing. Thus [15] presents in its motivation the ever-growing need for more understanding of data science. In this field elementary ambiguities as simple as f_X remain: When just found in a web-page describing physical movements, f_X is likely to mean the derivative of the function f in the direction of the vector field X ; if the page describes statistics, it is likely to mean the probability density function of the random variable X . What happens if found in a page that describes the statistics of the movement of particles in the air? It is not clear yet. The personal experience of the author in teaching probability and statistics has shown that the notations of these two neighbouring fields, which also use linear algebra, geometry, and analysis, would be much less confused if it were reinvented.

6 Implications for the construction of learning softwares

Having shown a glimpse of the breadth of the diversity of mathematical notations, we turn to the need of software developers to be able to represent the mathematical notations to express mathematical knowledge in a way that allows operationalisation, e.g. when planning a content project or a learning software.

For example, we expect that makers of computing systems to organize how they define mathematical notations in such a way that both the notations dis-

played in results and the notation used for input look similar, e.g. that the look of buttons is the same as in the rendered formula.

- A first approach is to hard-code notations: Examples of one-size-fits-all applicants are numerous. Pocket calculators have neglected the difference of decimal point, accepting that the period “.” is universal, and mostly do so for trigonometric functions. Similarly, the formula input with a pen in Microsoft Windows introduced with Windows 7 is an example of a tool that has been designed with the western culture in mind and, according to his author [22], would require a complete retraining if it wished to be adapted to another culture. We claim that the cognitive costs of translating the mathematical notations to that of a different culture (mostly, the Anglo-Saxon culture) is similar to the cost of entering the formulæ in some programming language, thus it is natural to expect a learning system to adapt to its learners’ cultures [21].
- Addressing few languages may be a small start: Wolfram|Alpha³ has been introduced in 2009 with a very broad set of classical mathematical tasks; contrary to the claim of its creator in 2012 [25] to go international soon, it only has introduced other languages very slowly (Japanese 2018, Spanish 2022, see [26,4]): Both these pages show that new languages are the result of long adaptation processes and go further than mathematical notations.
- More advanced solutions exist offering multiple languages: Systems of translations between formulæ encoded in an abstract format and their notation-language (e.g. MathML-presentation or LaTeX) can be used by mathematical software systems. They allow the abstract format (e.g. OpenMath which can be both calculated upon and rendered). Ideally they also allow them to be input. To perform these translations, a complex set of rules can be maintained; examples include [19,18,2], it is the set of notation-rules each of which associates a pattern in the OpenMath tree with a corresponding rendering in MathML-presentation. These sets of rules may also include the user-interfaces buttons of an input; the preferability of some symbolic constructs compared to others (e.g. to facilitate the recognition or to include the button in a more readily accessible place than the other). This approach is, to our knowledge, the only possibility to encode notations abstractly and completely.

How many sets of notations should be maintained? One first approach to decide on the amount of notations, is to create a set for each language: This set must cover all operators and may be very resembling to others but must be in a position to take in account the adaptivity for the numbers’ format (a normal expectation of users) as well as classical symbols.

Learning software makers may take the variation further to ensure that the cognitive load of users remain devoted to their learning. Each of the symbols used should be screened for their relevance for the target audience. This is probably

³ Wolfram—Alpha is a recognized search engine for mathematical questions. See <https://wolframalpha.com>.

best done by content authors with teaching experience in the field. For example, a math teacher would be able to identify, depending on the age, if the symbol for division of two numbers should be as a fraction (as in $\frac{24}{3}$), using colon (as in $24 : 3$) or using the \div sign (as in $24 \div 3$) (the age of the target user should be the decision basis) or if the root of -1 should be written i or j (the activity field should be the decision basis).

Following the freedom to define new mathematical notations, which was already stressed in [10], it is probable that new mathematical notations, which are not yet planned by existing infrastructure of notations may appear. Software makers should make this notation agility possible as a systematic change of notation may bring a considerable cognitive strength.

How many sets of notations per language and where should notations be gathered? This question is not much researched. The approaches of OpenMath or LaTeX described above has permeated MathML-content and follows the distributed practice of the semantic-web encoding of ontologies through RDF so it seems appropriate. The idea of each is that notations are where symbols are being defined or at least point to it; indeed OpenMath has a notion of content-dictionary which authors can create. However these approaches only live in a single encoding. A more general approach would be to set the expectation of a notations' table for each work of maths and that elements of this table are individually linkable so it is possible to augment the display of a formula with a link to the notation. Should such an approach become widespread, it will be much easier to discuss about notations and thus communicate about it, e.g. to take distance or to adopt.

7 Conclusion

In this paper we have illustrated the complex diversity of mathematical notations which is based on multiple cultures built by the traditions of mathematical knowledge texts. The diversity of the texts is rooted in the learning process of every reader who has learned the notations by learning the concepts around them and the allowed manipulations using them (their “haptics”). Because of this strong binding between learning and understanding the notations of a mathematical formula, we have argued that content specialists are needed to decide how to render mathematical formulæ in a way that is relevant to the readership.

Through multiple examples of diverging cultures, be them based on the language or on some other contextual information, we have shown the very rich set of notations and have argued that the set of relevant mathematical notations for a given software must be extensible and defined by experts close to content authors instead of employing general references such as [1]. As illustrated in the consideration of the history of mathematical knowledge such as [20,8], the evolution of mathematical notations has been an important fuel for the evolution of mathematical ideas. We have demonstrated that this invention potential is still there with even a creative industry aiming to explain mathematical formulæ better, for example in this systematization of mathematical augmentation [15].

Approaches to organize mathematical notations in interpretable bodies of knowledge are not yet widespread. The only initiatives we know of aim at rendering OpenMath or LaTeX [19,18,2]. It is likely that other collections of notations will appear in an effort to encode the diverse bodies of notations. This remains future work.

Among the current evolution of software handling mathematical notations, the development of recognition systems and datasets based on machine learning is growing. Such a system as [23] is working by grasping the context and is able to recognize sufficient information so that the symbols' interpretation, and probably more, is automatically detected. Doing so likely induces detecting the mathematical culture of the set of notations and concepts in the paper and in papers it depends upon. Expliciting the stacked effect of recognized cultural influences could have a similar expression than that of combining machine learning models by finetuning them on further annotation sets. Anchoring the culture ancestry goes along the lines of the suggestion of Timnit Gebru whom, when asked how to stimulate a more open participation to the body of science, suggested that each scientific contribution makes the effort of declaring all of the inspirations and background texts of the authors; this way induced biases and untold assumptions could become easier to question [14].

Such a proposition goes in the same direction of tracking the many cultural influences so as to better understand an argument. This paper has demonstrated the need to make the decision of mathematical notations, and the power to invent new notations, in the hands of subject matter experts close to content authors and leave the door for newly invented notations.

And thus, science in the hands of the future generation can be seen to be promised to a bright future:

[...] enabling imagination to wander far beyond the tangible world we live in, and into the marvels of generality.
[20, chap 6, end of the 16th paragraph].

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From Concept to Teaching Resource

Paul Libbrecht¹[0000-0003-3176-3361] and James Davenport²[0000-0002-3982-7545]

¹ IU International University of Applied Sciences, Germany paul.libbrecht@iu.org

² University of Bath, UK masjhd@bath.ac.uk

Abstract. Through a historical overview, we show how a scientific innovation can become a part of knowledge which is mature enough to be taught: set theory. This example shows through explicit representations across history how much richer knowledge is needed in order to be taught and, thus, to be made into a tutoring system than its scientific basis. The historical process explains us how an idea needs to be adjusted, to be turned into practical exercises, notations, teaching units, and practical recommendations to include it into the curriculum standards. The varying representations are sketched, be them notational, graphical, haptic, textual, or even part of artists productions.

The paper sketches paths of how the cultures developed around a mathematical concept needed to evolve in order to become teachable.

Keywords: Mathematical Cultures · Learning Resources · Teaching Practice · Mathematical Concepts · Notations · Set Theory.

1 Motivation

Our society has evolved thanks to the evolution of knowledge powered by new concepts and ideas created by scientists. The need for science is becoming bigger every day with the science subjects themselves evolving rapidly (consider the growing appearance of “Data Science” which emerged in 2001 but is now becoming a needed competence in most engineering subjects). To support this evolution, the educational systems regularly must adjust their curriculum standard, introducing new topics, adjusting some and removing others. These changes requires the educational landscape to be adjusted: teachers’ knowledge needs to be adjusted as well any support resources such as textbooks, software, or even the mere writing tools. A culture around the original ideas needs to be built.

We thus ask ourselves the following research question: What are the paths between the emergence of a scientific idea to its applications in the classrooms? We hope this example will be useful to others as they change, or respond to changes in, curricula. Our interest lies in the mathematical knowledge with a special interest on the evolution of the mathematical notations, this set of customs that forms the carrier of the formal knowledge of mathematics. This question is important when planning learning resources such as intelligent tutoring systems, quiz systems, or simple works made of multiple web-pages. Only with this in mind is it thinkable to receive the mandate to create teaching resources

for a subject where little teaching experience is available. Such an issue arose in England in 2014, when teaching computing, including programming, suddenly became compulsory for ages 5–14, and teachers were confronted with mandates from management such as “you teach Powerpoint, now teach Python”.

Many domains of mathematics have seen an introduction within the last decades, most promoted by the steadily growing need of the technology industries. As simple examples, one can mention the general domain of analysis, with the focus to calculus now broadly taught across many mathematics secondary schools (but only introduced at Harvard in 1738 [15]), and still controversial in USA in the 20th century [26]). One can also mention probability and statistics whose teaching in schools was patchy in the U.K. at least in much of the 20th century [5]; in France [24] and many other countries this domain was only introduced at the turn of the millennium. Both these broad fields introduced new teaching challenges. Both contain a large body of mathematical literature, are connected to many other topics of the mathematics, and can be supported by pedagogical knowledge. Their development uses a language of notation which subtly diverges at least along languages. Instead of exploring these large domains, we prefer to restrict to a theory which is smaller and probably has a more homogeneous representation: set theory. This also has a distinctive notation (unlike, say, Data Science), which makes tracking its evolution easier.

1.1 Related work

While several research efforts have been made into the history of the curriculum standards (e.g. [6] or [10]) we know of few works that have employed the history of notation to relate the history; most notably the work of studying the evolution of symbols on mathematical concepts [18]. We also observe that many mathematics learning tools are rooted in particular historical, pedagogical, and national contexts and propose to use the history to take a birds’ eye perspective. Curriculum standards debates have been often bound to various political and influence attempts as demonstrated in [30]; our case study looks at the content and knowledge in a much more factual fashion.

1.2 Paper’s organization

Our paper is a case study on the introduction of set theory. It first depicts a few essential qualities of a mathematics concept so as to make it into a teachable concept. Based on this characterizations, which show the cultural roots of a concept, a precise historical walk is depicted for some of the elementary concepts of set theory. The paper then envisions alternative ways that the concepts could have grown with and the probable implications for current notations in current communication systems.

1.3 Decomposing a Mathematics Concept

The introduction of a mathematical concept among the learning objectives can have multiple facets which we try to enumerate here: We describe essential ele-

ments of a mathematical concept. A mathematical concept is, here, any formally defined idea that allows mathematical operations and has mathematical properties, for example the concept of matrix (2-dimensional arrays of numbers), of limit of a real function (an operation on real functions to evaluate approaches of its values), of set defined by a condition (a notation to describe formally a set by expressing a condition on its members), or of maximum likelihood estimate (a technique to estimate the parameter of a supposed probability distribution).

Typical facets of a mathematical concept include the following:

- Name: How is it named? how does it decline itself in the various grammatical forms?
- Definition: How is it defined?
- Properties: What are its properties? (proven or suspected)
- Connections: How does it connect to others?
- Notations: How is it graphically represented as notation?
- Properties and Connections Notations: How are the properties or connections represented? (how can you compute with it?)
- Applications: What can you apply or deduce from it, or with its help?

These facets are important for the sole objective of understanding the concept. An example description of a mathematical concept could be the Wikipedia page [https://en.wikipedia.org/wiki/Complement_\(set_theory\)](https://en.wikipedia.org/wiki/Complement_(set_theory)) or the classical book on set theory [13, p. 17] defining the complement of a set.

While one may expect the mere definition to be already the essence of the concept, these facts already show how much connected to other mathematical concepts a mathematical idea is: The concepts, be them presented in original article forms or as an introductory summary, all live within the culture of mathematicians of their times which encompass language (names, declinations), knowledge (definitions, properties...), arts (in particular, graphical representations), customs (ways of saying and of noting), capabilities (acceptable and not acceptable operations), and habits (classical resolution steps, ...).

When they are explained or presented, they do so in a way that is connected to a network of concepts; these can be represented by references to other scientific works but also other more digestible references. It is not rare that a concept explanation becomes refined and reformulated. Textbooks and articles that describe the concept without the claim for originality can offer refinements and iterations, distillation. This helps better connections, easier proofs, better operations through notations. This maturity process can be well perceived for the arithmetic operations when reading the book [18] which explains, in particular, the impact of notations to empower the conceptual thinking.

1.4 Teaching a Concept

As every piece of knowledge, a mathematical concept can become the subject of teaching: By a teacher on a blackboard, within a digital communication channel or by fully automated tutorial software: All these learning methods employ similar facets of the mathematical knowledge concept.

Before a concept can be taught, an even longer maturation process happens. The first step is in recognizing its importance for currently relevant societal goals. As of this writing, this happens strongly with the many linear algebra and analysis processes behind machine learning: The need for mastering the mathematics behind machine learning algorithms and possibly devising new applications for many trained engineers is currently strong (a simple example could be seen in [17]).

Earlier needs can be interpreted such as the need for modular arithmetics around multiple computer science courses to support encryption or the need to calculate more precisely that stimulated Charles Babbage and Ada Lovelace to create the Analytical Machine.

The second interconnection step relies on the pedagogical preparedness of the concept: Depending on the amount of evolution the concept has gone through, it can take many decades before it becomes applicable in teaching situations. Teaching a concept involves that the teacher or software is able to represent and operate on the concept but can also react to many correct or erroneous representations or operations done with it. This requires the software or teacher to connect far broader realities than that done in the applications or properties proofs of the concept. The example situation of Sean's even numbers' definition in [2] and its articulation of the *mathematical horizon* show well how much broader the scope of teaching is than that of proving or applying is.

This maturity level is anchored in the same cultures but is enriched by the more education oriented cultures: The fact that the concept is manipulated in classrooms means that many alternative ways to think of it, to express it, to manipulate it, and to operate with it will be thought of. School teaching as well as educational software are two representations of the theory which require more completeness than just explaining the concepts in an article or book: If considering the culture around a concept as the set of ways to express and manipulate a concept, including how to write it, how to read it, how to input it, how to operate on it, then both educational software and teaching practice connect to a much broader culture than the mere expert explanation or even simple textbooks.

The risk of minimizing this extra culture and to consider that teaching only requires the application of the core knowledge is non-negligible as the introduction of new topics posits that the teachers master the topic. An example situation has been told us as a story of parenthood when a 10 years old child in Ontario (Canada) was required to count the probabilities of the sum two regular cubic dice: The teacher, then, suggested to use a table of all two dice values but counted the double matches as occurring in one sense and the other (so, to get the sum of 4, one would use the pairs $(1, 3)$, $(2, 2)$, $(2, 2)$, $(3, 1)$). Interrogated by the parent, the teacher's answer was: We let the vote decide if we should count double matches twice (this vote was done in the classroom and when learning the concept at the teacher's university) [22]. This story shows well how much challenged a teacher can be and how much non-mathematical the knowledge can be developed: Beyond the knowledge impact, the essentially non-proof-based ap-

proach used by the teacher may lead to ill-founded mathematical assertions being used in the children’s future.

2 History of a concept introduction: the set notations

Set theory, and the notation that goes with it, are engrained in (university-level) mathematics today. But it was not always so.

2.1 The theory of set theory

Set theory, as a separate mathematical discipline, begins in the work of Georg Cantor. One might say that set theory was born in late 1873, when he made the amazing discovery that the linear continuum, that is, the real line, is not countable. [1]

Hence the subject is essentially 150 years old. But it did not spring fully-formed from Cantor’s head: We still had Russell’s paradox [23] and others to deal with. The first abstract formalism of this set theory (though we should not ignore the works of Boole [3] and their graphical development in the form of Venn diagrams [28]) appeared in 1908 [31], but Zermelo–Fraenkel Set Theory as we know it is barely 100 years old [11].

The development of the notation did not wait for the abstract formalisms to be developed. The notations \cap and \cup were in use in 1888³, and [21, p. V] introduced a set membership symbol, using a regular ϵ rather than today’s \in .⁴ An example of early notation is in figure 1.

quae eodem tempore sunt a et b ; $a \cup b$ est classis individuis constituta qui sunt a vel b .
 47. $a, b \in \mathbb{K} . \supset . \omega \epsilon . a b : = : \omega \epsilon a . \omega \epsilon b$.
 48. $a, b \in \mathbb{K} . \supset . \omega \epsilon . a \cup b : = : \omega \epsilon a . \cup . \omega \epsilon b$.

Fig. 1. An early presentation of the concept of inclusion of set theory in [21, p. XI].

However, these notations were essentially confined to logic and set theory, and did not greatly impact “mainstream” mathematics. For example, the second author’s father, who went to university in the 1920s, did not naturally use the

³ [20, §2, pp. 1–2]. According to [4, Vol. 2, p. 298] this was the first definition.

⁴ <https://mathshistory.st-andrews.ac.uk/Miller/mathsym/set/> is slightly surprised at this, and the fact that Peano’s existential quantifier was a rotated (the original says “backward”, but this is impossible with 19th-century printing technology) E *with* serifs. But all Peano’s “new” symbols were existing characters being used in unusual ways, rather than asking the printer to make new symbols. For example [21, p. XI] uses a rotated C for “subset”.

notation. It was probably the Bourbaki texts that popularised these notations in mathematics outside set theory/logic. Apparently these texts also introduced the \notin symbol. From this point, we can say that set theory notation became the notation of mathematics.

2.2 School-level set theory

In the 1960s, under labels such as “New Mathematics”, the notation (at least \cup , \cap and \in) and the elementary use of set theory was introduced into experimental school curricula, at least in U.S.A. and U.K. Gradually, more curricula would adopt these, but often as options. This would make life difficult for university teachers: the second author often encountered classes where roughly 2/3 had encountered these symbols, but 1/3 had not. It wasn’t until 2017 that their teaching was required⁵ (for those 16–18 year olds studying mathematics) in England [9, OT 1.3]. The precise set of symbols required was $\cup, \cap, \in, \notin, \subset, \subseteq, \{\dots\}$ and \emptyset .

In French speaking Europe, and a few other countries, “Modern Mathematics” (mathématiques modernes) were introduced in the 1960s too. It had as most important premise to make set theory the basis of most other mathematical concepts starting as early as the age of 7. But the introduction was so radical that it was criticized for the social inequalities it created and demised less than 20 years later [6,10].

It is worth noting that, just as Venn diagrams preceded \cup etc. chronologically, they do pedagogically: the same reforms to mathematics teaching in England that introduced the symbols for 16–18 year olds made Venn diagrams part of the curriculum for 11–14 year olds [8, KS3], Venn diagrams and mappings with them were made at around the age of 11 in modern mathematics.

We can see a similar development in the most widely spread softwares used for calculations such as computer algebra systems: those of the 1960s and 1970s (CAMPAL, Macsyma, Reduce etc.) do not have “set” as a built-in concept, whereas those of the 1980s (Maple [12, pp. 5-6], Mathematica) do. Reduce had set functionality added in the the early 2000s. Computer algebra systems are the standard tool used to perform mathematically correct elaborate calculations in integrated mathematics teaching systems that aim at least at the secondary school level at least for their ability to perform symbolic evaluations of the students’ answers.

2.3 Possible Causes

There seems, unfortunately, to be little discussion as to why set theory has been kept away from school that long. We can conjecture that the difficult paradoxes

⁵ The second author was a member of the committee that made this decision (formally, a recommendation to Government), and its principal proponent. It succeeded as part of a more general move to reduce the number of options and increase the compulsory core.

that a teacher can fall into are an undesired trap. For example, Russell's paradox, which illustrates classes that should not be sets, requires, to be discussed, a very clear set of axioms.

We can also conjecture that set-theory was not prepared sufficiently in its graphical expressions with reference works such as [13] having ignored Venn diagrams whereas this notation is the essential representation deemed useful in school books. This gap between theory and teaching is very visible in figure 2.



words, g is a function from X onto the set X/R of all equivalence classes of R . The function g has the following special property: if u and v are distinct elements of X , then $g(u)$ and $g(v)$ are distinct elements of X/R . A function that always maps distinct elements onto distinct elements is called *one-to-one* (usually a *one-to-one correspondence*). Among the examples above the inclusion maps are one-to-one, but, except in some trivial special cases, the projections are not. (Exercise: what special cases?)
 To introduce the next aspect of the elementary theory of functions we must digress for a moment and anticipate a tiny fragment of our ultimate

Fig. 2. Two very different representations of the concept of one-to-one mappings: on the cover of the exercise leaflet of [7] (for pupils of about 8 y old) and among other concepts in the classical set-theory book [13, p. 32] (for scientists).

3 Alternative Ways Set Theory Could Have Been Represented

From the long history of the concepts of sets, more than 150 years, one can see that many ideas could have emerged being different. We propose ideas that indicate possibly different evolutions.

In terms of notations, alternative symbols could have been used: A more Venn-diagram-like notation could have been used as in the following equation. It is likely that the typesetting difficulty prevented this:

$$\textcircled{4n | n \in \mathbb{N}} \cap \textcircled{3n | n \in \mathbb{N}} = \textcircled{12n | n \in \mathbb{N}}$$

Taken even further, the intersection symbol could have been presented by intersecting the rounded boxes as in the following:

$$\left(4n|n \in \mathbb{N}\right) \cap \left(3n|n \in \mathbb{N}\right) = \left(12n|n \in \mathbb{N}\right)$$

And a similar graphical construction could be invented for the union operation. Such an alternative notation can be fully formalized. Learning software makers or animation makers could, nowadays, with such a notation, offer a much smoother transition between the formal statements such as above and the Venn diagram representations that have been widely used at schools thus becoming a much more easily rememberable concept.

Many alternative ways might be more compatible with other approaches. For example the first set above can be written as in $\{4n|n \in \mathbb{N}\}$, $\{k|\exists n \text{ with } k = 4n\}$ or simply using ellipses $\{0, 4, 8, 12, 16, \dots\}$. Each of these representations is in use but provides different ambiguities or abilities to solve. As can be seen in this StackExchange question [16], the desire for richer learning materials in set theory still remains and few stabilized educational studies have been realized as shown in [19].

Explanations of concepts such as the infinite sets as in the video [29] also provide example of expressions using a much broader vocabulary that expresses sets and their operations with graphical animation methods. The popularity of the 3-blue-1-brown video series [25] shows that animations to explain mathematics can impact the understanding of many. This new set of expression means impact the mathematical cultures deeply: new writing methods need to be created, new ways of consumption are expected, new notations are likely to appear. Learning software projects are all subject to this evolution and may be carriers of new such expressions faster than school books have developed. This implies that it may become the role of learning software vendors to innovate in the introduction of notations.

4 Potential Learning Processes for Future Concepts

New mathematics ideas flourish, with new approaches to manipulate the mathematical concepts. The community of mathematicians is active in creating new concepts or rewriting existing ones and it will grow. In this paper, we have provided the example of a long-winded set of mathematical concept which went from mere ideas into a practice that will be soon teachable by tutoring systems. We have sketched evolution of the cultures around the concept so as to demonstrate how much transformation and additions a mere scientific idea can need to become teachable. It is likely that such processes appear further.

Among the current evolutions of mathematical knowledge, algorithms are having greater roles; this includes several proofs but also includes algorithms for mundane tasks such solving equations or calculating optimal values and let computers do a part of that algorithm with trust. We contend that this, again, will need different forms of expressions so that proofs can be exchanged and learning resources can be built.

Two trends are especially affected by the evolution of technology: digitization and internationalization:

While some mathematicians still consider they should only want to express mathematics with a pen-like device. Digitally-expressed mathematics is there for learners and for practicing mathematicians. It brings other affordances (e.g. distance learning) and an amount of simpler and more expressive ways of explanation. As an illustration, a typology of *mathematics augmentations* has been started so as to stimulate the field [14]. It is clear that animations will help connect operations with geometric perception and that more such techniques will fuel the knowledge.

On the other side, the need to support *wandering readers* will grow: far from the sustained participation to a learning channel that pupils have in regular classes, we contend that users will evolve with even more cross-navigation actions: they will navigate to particular places in websites or open books at a definite page following an index. This brings a bigger visibility to the need for referencing topics and for an international exposure. Similar to some established multilingual efforts such as [27], culturally correct translations will be expected and counted upon, including taking in account all notational conventions. While, as could be seen with set-theory for which the emergence we reported has used at least four languages (German, Latin, Italian and English), the language is not so important for a scientific elaboration, the language is, on the contrary, an important cognitive factor for wandering readers who expect as much as possible a closeness to their own (notational, language or conceptual) cultures.

These two trends may bring considerable strengths in bringing mathematicians' concepts, that are so much needed for the development of societies, faster into learning resources. We contend, further, that they may help bringing more subject specific exchanges and web a more dense mathematical horizon knowledge.

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Lots to think About: Looking through Hall's Cultural Lenses to Analyze an Introductory Computing Course

Gustavo Yuji Sato^{*1,2}, Lavínia Rafaela De Marco³,
Rachel C. D. Reis¹, Isabela Gasparini³, and Roberto Pereira¹

¹ Federal University of Parana, Curitiba PR , Brazil
{rachel, rpereira}@inf.ufpr.br

² Federal University of Technology – Parana, Francisco Beltrao PR, Brazil
*gustavosato@utfpr.edu.br

³ Santa Catarina State University, Joinville SC, Brazil
laviniarafaelademarco@gmail.com, isabela.gasparini@udesc.br

Abstract. Culture affects how people behave and, consequently, how systems should be designed. This paper presents a work in progress using Lewin's Action Research Model to analyze the cultural context of a gamified introductory computing course. It presents the analysis results using Hall's Primary Message System (PMS) as an analytical lens. The results from this analysis will be used to inform and plan changes for gamified resources in the course. The course was designed to include culturally relevant elements in its syllabus, presenting basic computing concepts and areas of study, putting ethical and social issues into discussion, and introducing students to the university context, teachers, and research laboratories. The paper exemplifies how the PMS can help understand a myriad of cultural issues and discusses how technologies can contribute to exploring aspects of the social context.

Keywords: Gamification · Culture · Teaching · Learning · Unplugged Computing · Introduction to Computing

1 Introduction

Culture can be defined as the collective configuration of the mind that distinguishes one group of people from others [17]. Such collective ideas can make people communicate in different ways [15]; and have different values, such as autonomy, hierarchy, and self-assertion to change the natural and social environment [34]. In short, communities worldwide exhibit different behaviors due to cultural influences.

These variations pose a problem: scientific and technological progress is marked by ignoring the diversity of perceptions that different cultures have, focusing only on studies whose population is Western, educated, industrialized, rich, and democratic [16]. In the educational context, Freire [12] argues that incorporating the unique characteristics of students' social context is essential

for learning, and content structured without consideration of the social context would merely represent a “cultural invasion” or “deposit of information”, and not an education that would enable the development of critical consciousness.

This paper analyzes cultural aspects in an Introduction to Computing course designed for first-year students. The course was gamified to promote students’ interest while bringing social and ethical issues into discussion. In this instance, game design principles are applied to an educational setting, adhering to Deterding [8] definition of Gamification: the incorporation of game design elements into a non-gaming context. Considering Lewin’s Action Research Model [24], the work in progress discussed in this paper is part of the evaluation step (Figure 1). Results from this evaluation activity will be used to inform and plan changes for gamified resources in the course.

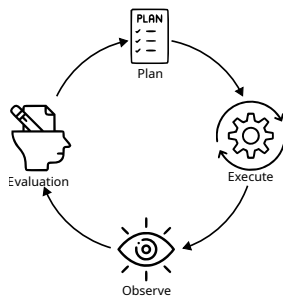


Fig. 1. Action Research Model

To analyze the cultural aspects of the course, it was used Hall’s Primary Message Systems (PMS) [15], also known as Hall’s Areas of Culture, which helps to identify relevant cultural aspects in different levels of formality. With this analysis, it is possible to exemplify how Hall’s PMS assists in considering the cultural domains relevant to students. Furthermore, the paper discusses how technologies can contribute to exploring other aspects of the social context.

2 Gamification

According to Schell [33], games create a system that involves challenges, rules, and clear objectives, requiring participants to seek solutions to progress and achieve goals. These results can be quantified (as points) and promote emotions, such as enjoyment, which is crucial in the learning process [22]. Bissolotti [5] provides a practical case of gamification, which consists of a child trying to avoid stepping on cracks in the floor during their journey home from school, thus making the return trip more enjoyable.

Gamification consists of a strategy that employs elements and design principles derived from games to engage and motivate people in non-gaming environments, fostering the development of learning and problem-solving skills [8]. This

approach can be applied in different contexts, such as healthcare, educational experiences, and business strategies, to motivate employees or boost customer engagement. Gamification should not be confused with Game-Based Learning, Simulation, or Serious Games, as they involve creating games and game-like experiences. On the other hand, gamification seeks to use design concepts similar to games [13].

Furthermore, there are gamification techniques that help participants develop new skills and enhance their motivation and learning. Among these, scoring systems are associated with the desire for reward; rankings also stimulate competition. There are also game levels, representing the player's progress and skill, giving him social prestige; finally, gifts, allowing participants to assist each other and engage in an altruistic practice [26].

3 Hall's Primary Message Systems

In this section, Hall's [15] Primary Message Systems (PMS), or Hall's Cultural Areas, will be discussed and used as an analysis lens for cultural aspects of the study. PMS consists of 10 areas, heterogeneous among individuals from different cultures, influencing communication. In this study, the learning process can be seen as communication within the academic community. These areas are inter-related and divided into three modes: formal, informal, and technical. The ten areas encompass: Interaction, Association, Subsistence, Bisexuality, Territoriality, Temporality, Learning, Play, Defense, and Exploitation.

Interaction is the activity that concerns how living beings interact with the environment. One of the most elaborate forms of interaction that distinguishes human beings is speech, accompanied by voice intonation, gestures, and writing, which is also outstanding in complexity due to the use of symbols. Other forms of interaction between individuals and environments determine how individuals relate, survive, explore their surroundings, engage with time and space, learn, have fun, and defend themselves. Therefore, interaction is a PMS that is interconnected with other other forms of interaction.

Association refers to how individuals interact with each other. Social animals create relationships through a pattern of association. Hall illustrates this with an example from the lives of a group of chickens, where a "pecking order" exists. A chicken at the top of the hierarchy pecks the others but is not pecked by any of them. The second in the hierarchy pecks all the chicken except one chicken. Every chicken pecks the one at the bottom of the hierarchy.

Subsistence addresses the essential habits for maintaining life, such as eating habits and the food acquisition. To achieve that, modern society has developed a complex economic system, sustaining itself through receiving wages in exchange for labor. Each culture holds different attitudes towards work, including the value assigned to certain professions.

Bisexuality refers to societal expectations placed on individuals based on their gender. In a broader sense, it can also be seen as *Classification* [35], reflecting

societal expectations placed on individuals based on factors such as ethnicity, age, and social class.

Territoriality encompasses space-related habits and how individuals appropriate and protect property. There are culturally defined spaces for working, studying, and playing. Furthermore, position in space defines meaning. For example, status can be indicated by the distance a person sits from the head of the table.

Temporality relates to how culture interprets the temporal relationship, the cycles and moments expected for specific events, and the historical process by which the facts happen.

Learning is related to how knowledge is transferred, formally or informally. Cultures may emphasize different forms of Learning, such as learning by doing, as an example of differences in formal education. Informally, knowledge about social norms and culture is passed on to children through behavioral models and mechanisms of reinforcement and punishment.

Play refers to activities driven by intrinsic motivation, enjoyment, and competition. Different cultures impose different locations (*Territoriality*) and moments (*Temporality*) for games.

Defense is how individuals defend themselves from hostile forces. Hall describes armies protecting against other societies, law enforcement protecting against violators of society's rules, medicine protecting against illness, and religion focusing on medical care and science in many non-Eurocentric societies as having broader roles.

Exploitation is the way individuals adapt to exploit the environment to obtain materials. In this case, humans use tools to facilitate *Exploitation* and money to exchange materials.

Each of these areas interacts with the others. For example, human interaction with the environment influences all other areas; play requires the right time and space to happen, and so on. Furthermore, these areas can be categorized into three modes of operation: formal, informal, and technical. Firstly, the formal mode, which is a well-documented norms, although not necessarily written, is explicit. For example, in a traditional classroom, students may be expected to remain seated, and when they stand up, the teacher prompts them to sit down.

Secondly, the informal mode is defined by undocumented norms, whose knowledge is passed on implicitly during individuals' interactions. For example, the child begins to imitate certain adult behaviors, such as how they walk.

Finally, the technical mode is defined by well-documented norms governed by logic. Generally, knowledge is passed in one direction during classroom interactions centered on the teacher.

4 Studied Context

The Introduction to Computing course is lectured at the Federal University of Parana (Curitiba, Brazil) to offer experiences through which first-year students have contact with different computing materials and topics, exercising essential

computing skills – both in the technical, social, ethical, and human values sense, helping students situate themselves in Computer Science. [29, 30].

Among the main objectives of the course is the development of abilities considered essential for computing [28], such as abstraction, decomposition, pattern recognition, algorithms, debugging/review, efficiency, reading, writing, synthesis, autonomy, collaboration, rigor, ethics and professional responsibility, project experience, systemic vision, problem-solving, and computer science domain knowledge.



Fig. 2. Pictures of historical computing figures on the department wall.

The course employs challenges that exercise computational thinking [41], using the unplugged computational thinking approach [3], along with a gamified structure [32]. The discipline is divided into thirteen phases, progressing weekly. At the beginning of the course, students create a character sheet indicating personal preferences (music, series, films, books, etc.) and distribute points in 17 skills expected of students [28], in the form of a self-assessment. In each phase, a challenge involves computational thinking; algorithms are written as flowcharts or text without using a computer. When completing each activity, the student claims experience points in a self-assessment. If the teacher approves the self-assessment, the student can redistribute the points on a role-playing-like character sheet.

In this course, each computational thinking challenge is contextualized within a narrative. This narrative aims to promote engagement and interest in the course, comment about relevant concepts and topics about the area and the course, and address non-technical issues, such as ethical and social responsibility issues [29, 30].

To this end, the narrative takes place in a future in which modern and technological society has collapsed due to ethical negligence on the part of computer science professionals, generating the spark for ethical discussions. In this future, the students become the main character who joins the “Computational Thinking League”, exploring the ruins of the post-apocalyptic computing department, trying to recover lost knowledge about computing and its history. In the narra-

tive, the students find locations and Easter Eggs within the department — for example, several paintings featuring historical computing figures (Figure 2).

Another strategy to enhance students’ learning in this course is Unplugged Computing [3]. Unplugged Computing focuses on Computer Science fundamentals, not focusing on programming but understanding core concepts without using the computer. It usually involves playful hands-on activities and tangible exercises to teach Computer Science, which can promote better social interaction [3].

In the analyzed course, activities using Unplugged Computing were used. Gamification and narrative assisted in making activities more playful. For example, the pictures of Computer Science historical figures, shown in figure 2, were used in unplugged activities. In one activity, students had to propose a flowchart (algorithm) to search for a specific frame size since every portrait had different sizes. In the narrative, the paintings were watched by a guard whose algorithm would search for a message hidden behind one of the paintings.

5 Analyzing the Gamified Course under PMS lens

This section will present the analysis of the cultural aspects of communication within the course. Figure 3 presents an overview of prominent cultural issues from the perspective of Hall’s PMS [15], presented in this section.

Throughout the course, from a technical point of view, students learn to interpret and represent their ideas in the form of algorithms using flowcharts. Formally, interaction is promoted by gamification mechanics (medals, experience points, phases, etc.), and informally, verbal and written communications are carried out between individuals, in addition to the interaction of students with physical objects in the environment. Interaction involves systems generated by any relationship between people and the environment. Therefore, all other PMS originate from interaction.

A vital communication area influenced by culture is the association between individuals. Informally, students collaborate to carry out the discipline’s activities. How this collaboration occurs is not clear to the teacher due to the distance caused by the power relationship. To understand this relationship, a unique game mechanic using medals is employed in the discipline. In one of the phases of the discipline, a medal can be received as long as a colleague nominates another student to receive it. For such a medal to be awarded, the student must post a message on the subject’s discussion forum explaining how the student helped him during the previous phases. While not impacting the subject grade, these medals serve as a collectible, fostering a sense of partnership among students. This approach was designed to strengthen relationships between students, and its unintended consequence was enabling the teacher to understand the associations between students.

In 2023, a class containing 108 participants in the Discussion Forum presented the behavior shown in the graph in Figure 4. The graph nodes represent forum participants, and the direction of the edges represents when a student nominated

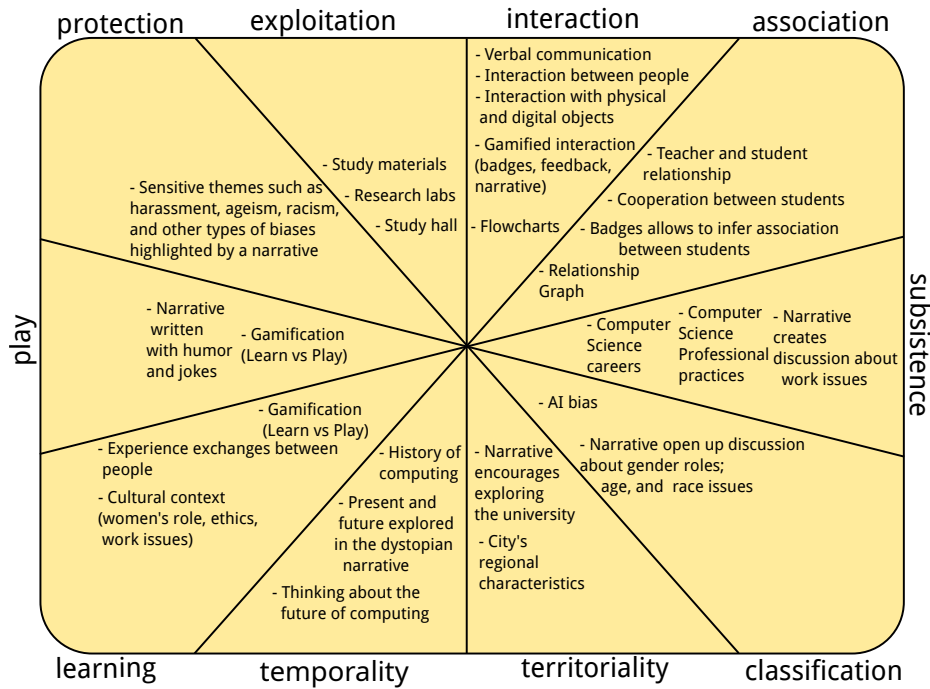


Fig. 3. PMS explored during the Introduction to Computing course.

another student to receive the medal. Participants who did not nominate nor were nominated to receive badges were not represented as nodes. The graph shows that, although students can cooperate in larger groups, most students work in pairs.

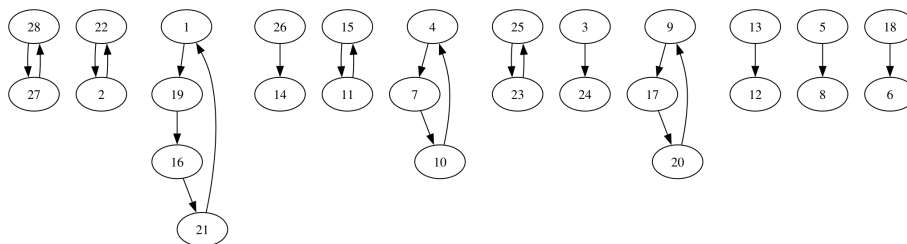


Fig. 4. Graph representing students indicating colleagues who help during their studies

For Hall, labor is crucial to sustaining life in the modern world. Labor done and exchanged for money enables obtaining the resources necessary to maintain life. Thus, an introductory computing discipline has an important role in

presenting a computer scientist’s main areas of professional activity and the practices involved in developing such professions. With that goal, a narrative is used, creating a space for discussing work issues. Narrative can be used to discuss controversial issues [2]. During the narrative, several reports are found that partially explain the dystopian future. The story goes that an e-wear device used to monitor the health of all individuals after a pandemic interfered with people’s motor functions simultaneously, causing several accidents, from plane crashes to nuclear power plant accidents. Thus, the opportunity arises to discuss various topics, such as:

- Lack of quality during software development, which makes it possible to discuss the consequences of errors in critical situations;
- Biased training base for artificial intelligence training. In the narrative, one of the causes of the accidents originated when wearable devices failed when used by minorities;
- Problems in unicorn companies, in which high investments are made due to unproven technologies and then budget cuts are made to ensure profit, compromising the ability to deliver the product;
- Business, selling, and marketing people interfering in software project management;
- Work schedule, tight schedule to deliver software, moral harassment at work, and gender discrimination;

Hall [15] argues that aspects of culture are passed on unconsciously in the informal mode of operation. During the interaction between students and teachers, the tone of voice, the choice of words, and the facial expressions shape how the model of the cultural norm is established in each individual regarding ethics and accepted behavior in a work environment.

This informal mode also allows for discussing gender issues, discrimination, and the role expected of people in society due to these factors. [4] highlights issues about the involvement of women in science and the gender gap in technology fields, such as computing. The narrative seeks to engage students to talk about those issues. As an example, the discipline includes, among the reports found in the narrative, news indicating that project problems in e-wear were caused by gender discrimination caused by the project manager being a woman.

The relationship between how a group relates to space is another point that affects communication within a culture. In addition to the narrative exploring the city’s regionalism, using facts and terms previously unknown to students from all over the country, the narrative forces the students to explore the university space, as one of the purposes of introductory computing courses is to integrate the students into the academic space. In one of the phases of the course, it is possible to find a secret message behind one of the frames (Figure 2) and another message in the book “Introduction to Algorithms”, left in the study hall of students.

These activities also have a strong relationship with the cultural aspect of exploration, the way a culture obtains resources and materials. To familiarize students with the resources available for scientific research, one of the course’s

activities is solving an “Einstein Challenge” (or Zebra Puzzle [14]). The “Einstein Challenge” is a problem in which you are presented with a list of constraints that must be obeyed to solve a riddle. In the case of the discipline, the riddle is who is the professor associated with each laboratory in the department. In addition to this riddle, the department’s researchers are also mentioned during the narrative, in which interviews are conducted about the problems of e-wear.

Exploring the past and the future uses temporality in the course. Students interact with historical computing figures present in the tables to explore the historical context of computing caused by the past. It is suggested that students complete a wiki with information about the characters. The future of computing is reflected in the narrative, asking what the consequences of a lack of reflection are when solving computing problems.

Learning and playing are combined to engage students during the subject used in gamification. Game design techniques attempt to engage students by offering challenges and provoking curiosity. For this, the narrative is used, the Easter Eggs that provoke the exploration of the spaces and the ‘easy fun’ [23] are awakened, while subjects that could be tedious if taken out of context are addressed. ‘Hard Fun’, described by Papert [27], are challenges that generate the so-called fun of completing a complex cognitive challenge.

6 Discussion

Different aspects of culture influenced what was desired to be communicated in the discipline, using gamified design. However, the challenge of planning the discipline is a problem that requires the analysis of the social and cultural context in which students are inserted [40, 12]. To face this challenge, the primary messaging systems may help analyze communication between students and teachers. This section will discuss problems when applying the solution in another cultural context.

Unconventional forms of interaction were used, considering traditional classroom standards; for example: Medals and points were used to give *feedback*; a role-play character sheet was used to track students’ progression, and it was also used to share personal preferences, like music taste, movies and sports; physical objects were used during the course promoted exploration of the department space. Knowing each other and the new department is essential to first-year students.

The narrative was used to engage students and teachers in discussing ethical issues. However, preferences for the use of game elements can vary between different cultures [36, 1], and even within the same group of people when age, gender, and personality characteristics [20] are evaluated.

Therefore, considering the cultural context when designing an educational experience, gamified or not, is essential. Reflect on whether gamification should consider the cultural context since the concept of appropriate places to play depends on culture [15]. In the context studied, gamification was used in first-

year students, but would gamification in higher education be accepted in all cultures?

One of the concerns during the gamification design was encouraging healthy relationships between students and being mindful when implementing mechanics that create competition. This design choice was made because excessive competition in gamification can negatively affect studies, with a drop in academic performance [37]. However, it must be considered that the intensity with which individuals compete is part of a cultural construction [34].

One of the challenges of a computing curriculum is the organization of a competency-based curriculum; in addition to ethical issues, “know-what”, “know-how”, and “know-why”, since these activities are transversal to scientific facts, practical activities, and cultural norms [11]. A narrative was constructed [29] aiming to encourage the discussion of subjects with such characteristics, contextualizing problems within the culture of students with problems common to various professions in the computing area.

7 Technologies and future ideas

Technology is the “application of scientific knowledge to the practical aims of human life or, as it is sometimes phrased, to the change and manipulation of the human environment”⁴. According to Feenberg [10], technologies reflect social values, interests, and power dynamics. Although the gamified environment is unplugged, digital technology can be explored to further emphasize the cultural elements present in the gamification design. This section will briefly discuss some possibilities for exploring digital technologies in the studied scenario.

A manual procedure was carried out to record the information in the discipline’s discussion forum to create the relationship graph in Figure 4. Using Educational Data Mining techniques [9] can help students organize such groups and identify learning style characteristics [9, 21].

Considering the importance of integrating first-year students with new spaces, ubiquitous computing (UbiComp) can help offer better experiences based on location, using barcodes, RFID proximity tags, and wireless networks[39]. In addition to ubiquitous computing, reality can reinforce interaction with space. For example, the work [31] uses Augmented Reality (AR) to integrate the narrative with the physical environment in a gamified context, using a geolocation system, [31] adds virtual characters to physical environments.

Combining UbiComp, AR, data mining techniques, and other modern technologies may add extra layers of possibilities to gamification. Identifying and considering students’ profiles can enable tailored gamification strategies [19], customizing students’ experience and increasing their engagement and motivation with the interactive and narrative elements most suitable to them [7].

The literature has shown that purposeful games (and game elements) can increase the effectiveness in educational scenarios, improving motivation and

⁴ <https://www.britannica.com/technology/technology>

engagement [18]. The cited technologies have the potential to offer new elements to trigger the students' interest in the narrative and the course, especially regarding their enjoyment and experience with the course [38]. For instance, virtual elements can appear as easter eggs, provide extra information, or help to keep students' track and interactions with the space. Physical objects may react to students' interaction, showing dynamic behaviors manifested in the virtual world. Different and additional parts of the narrative may be delivered to students according to their progress and experience.

Finally, with more technical apparatus come more possibilities to gather data and evaluate students' social interaction, immersion, enjoyment, presence, satisfaction, curiosity, etc., [6]. Evaluating the students' experience in such a rich scenario would be an interesting and challenging task, where it could be combined or extended common HCI approaches, especially those more used in the Brazilian scenario [25].

8 Conclusion

This paper analyzed essential aspects of culture in light of Hall's PMS in a study contextualized in a gamified subject introducing computer science. When the discipline uses elements of the student's social context, such as information about the university campus, professors, and laboratory, simultaneously exploring concepts, facts, and computing problems, it combines different elements for a situated learning experience.

Considering Hall's Culture Areas, it is possible to design a course that is mindful of cultural contexts, encourages students to explore space, uses unconventional forms of interaction, promotes healthy interaction between individuals, discusses ethical issues, professional problems, historical issues, and gender problems, and creates in students an intrinsic motivation to study—that is, makes studying fun.

This paper evaluated a gamified course in Lewin's Action Research Model, considering culturally relevant elements. As future work, it is expected to use more conceptual technologies - such as new ways of gamifying the subject - and new digital technologies, which make it possible to explore students' social and spatial interaction.

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Using AI for Assessment in African Languages Learning in Primary Education

Arielle Kitio Tsamo¹, Paulin Melatagia Yonta^{1,2[000–0003–3479–2627]}, and Sherelle Kana Azeuko³

¹ Department of Computer Science, University of Yaounde I, Cameroon

² IRD, UMMISCO, F-93143, Bondy, France

³ National Advanced School of Engineering of Yaounde, University of Yaounde I, Cameroon

{arielle.kitio, paulinyonta, kanaazeukosherelle}@gmail.com

Abstract. Language acquisition assessment involves evaluating fluency, intonation, coherence, vocabulary, conjugation, and grammar. The learning of national languages, which is the support of the local culture, is nowadays a priority for several African governments. In Cameroon, with over 200 national languages from different linguistic families, implementing this assessment in schools is challenging due to limited teacher capacity and varying student native languages as well as reading deficiencies. With the lack of adequate tools for early assessment and remediation of basic reading skills, it is impossible to determine whether a student’s poor academic performance is due to a lack of decoding skills, language proficiency, or insufficient knowledge to answer questions. To address this, an automatic speech assessment solution leveraging Natural Language Processing (NLP) could assess students in their mother tongue, enhancing training efficiency. AI enhances natural language processing by providing techniques and tools to leverage text and speech in many applications. In this paper the development of AI models for the assessment of learning African languages in primary education in African countries (particularly in Cameroon). We are proposing guidelines to deal with the linguist, the lack of guidelines for the learning assessment and a few data challenges of these languages. A generic new framework of skills assessment based on the level of learning task-related deficiency is also proposed to overcome the limit of the classical assessment approaches. The trained AI models for automatic speech recognition will be integrated in the implementation of this assessment approach.

Keywords: Automatic Speech Recognition · African Language · Automatic Assessment · Primary Education.

1 Introduction

According to a study conducted by the World Bank, 77% of children at the end of primary school age cannot read and understand a short story (compared to 58% for the average of comparable income countries). Factors that hinder quality

include, among others, an unfavorable school environment in which children operate, inadequately adapted curriculum content, and the shortage and poor use of trained teachers, which negatively impact supervision rates.

The main reason for such poor results at the end of primary school is that the instrumental skill of reading has not been mastered by pupils at basic levels. As students grow older, acquiring reading skills becomes increasingly difficult. Students who have not learned to read in their early years are likelier to repeat grades and drop out of school. The opposite result is observed for children who achieve good results from the beginning of their schooling [10]. Therefore, in the absence of early remediation of basic reading skills, it is impossible to determine whether a student's poor academic performance is due to a lack of decoding skills, language proficiency, or insufficient knowledge to answer questions [2]. Furthermore, When it comes to learning to read, students in the same class have different levels of deficiency. For example, in the same class, you can have students who can't identify graphemes, while others have difficulty with invented words and others with reading/listening comprehension. In the actual context of overcrowded classrooms, it is therefore extremely difficult for a single teacher to monitor and remediate student learning on an individual basis.

African countries are becoming increasingly supportive of maintaining linguistic diversity. Due to political, cultural, and/or social reasons, many African governments are implementing multilingualism policies centered on their local languages. Last year (2023), in Mali for example, the political situation led the Government to demote the French language from the *official language* to the *working language*, and decided to promote the use of local languages in education[16]. In 2018, the Government of Cameroon decided to introduce national languages and cultures courses in primary and secondary school curricula [9]. Teaching Cameroonian languages and cultures is essentially based on oral and reading skills. The actual school environment is such that it is very difficult to implement this assessment. There are more than 200 national languages in Cameroon, belonging to different linguistic families. A study carried out between 1960 and 2005 found that 85 (out of 200) national languages were mentioned by the people surveyed as the languages in which they had become literate [1]. Indeed, in a classroom, we have an average of one teacher to 40- 60 students. The teacher speaks and understands no more than three (03) languages; on the other hand, there are more than seven (07) different languages spoken by the students. It is therefore practically impossible for a single teacher to assess the progress of his or her students' reading skills (each in his or her native language). Furthermore, even when concentrating on the same native language (between students and teacher), we face the same challenges as described in the previous paragraph: in the same class, students have different levels of reading deficiency.

Learning outcomes (and specifically reading outcomes) cannot be improved without rigorous systems capable of generating the required learning data. In other words, learning cannot be improved without adequate measurement of progress and regression in reading skills. It is, therefore, necessary to make systemic use of learning assessment data to assess reading skills, to evaluate teaching

methodologies and reforms, plan remedies, and allocate resources accordingly. Automatic speech assessment solutions leveraging Natural Language Processing (NLP) could assess students in their mother tongue, enhancing training efficiency. AI enhances natural language processing by providing techniques and tools to leverage text and speech in many applications. In this paper, we are proposing 1) a generic new data-driven framework of skills assessment based on the level of learning task-related deficiency, 2) guidelines to deal with the linguist, the lack of guidelines for the learning assessment and a few data challenges of these languages.

The remainder of the paper is organized as follows: Section 2 is dedicated to a state-of-the-art review of existing solutions for assessing basic reading skills. In Section 3, we propose a framework for the use of AI for the systematic assessment of reading skills. In Section 4 will focus on how this new protocol can be used for learning African languages using Automatic Speech Recognition (ASR) models with a specific case tested in Cameroon with level 2 primary students. Finally, we provide a summary and concluding remarks in Section 5.

2 State-of-the-art

2.1 Early Grade Reading Assessment

Children who achieve good results in reading from the beginning of their schooling have increasingly better results[3]. The differences between students who have mastered basic reading skills and those who have not continue to widen over time [2]. Large-scale assessments are designed with the explicit aim of obtaining information about student performance and education systems. Examples include PIRLS, PISA, SACMEQ, PASEC, and LLECE (Fig. 1 presents definitions).

The tests associated with these programs are designed to measure trends in literacy so that comparisons can be made between countries or track changes over time within the same country. In addition, these assessments require mastery of basic reading skills (since they use passage reading), which may limit their relevance for assessing reading skills at the earliest levels of schooling. To address this gap, early-grade reading assessments (such as EGRA) have been developed (Fig. 2). These individually administered assessments are presented as being faster and less costly than other international assessments [10].

EGRA (Early Grade Reading Assessment) methodology is designed to assess students' reading skills, focusing on initial reading acquisition. It helps to identify gaps in reading skills and to design targeted interventions to improve learning at the classroom level, unlike other methodologies like PASEC (see Fig2). In other words, it is a diagnostic tool that helps teachers and decision-makers to evaluate the effectiveness of reading teaching programs.

The baseline data for *indicator15*⁴ specifies that less than one-third of developing countries have primary learning assessment systems that meet qual-

⁴ Indicator introduced by the Global Partnership for Education (GPE) to monitor the "Proportion of developing country partners whose learning assessment in basic education meets quality standards"

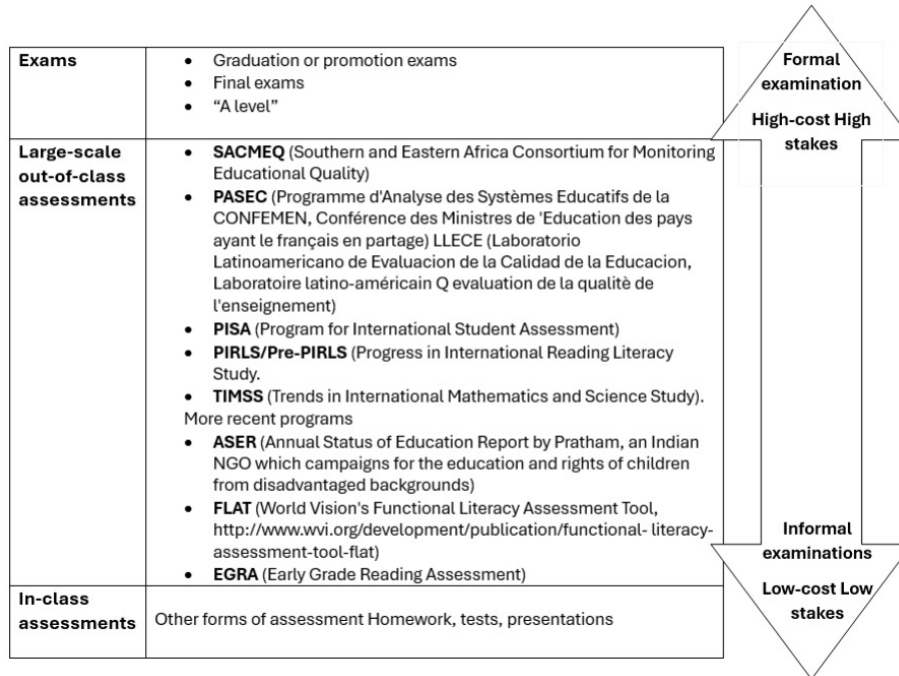


Fig. 1. Different assessment models[14]

	EGRA/EGMA	PASEC
Objective	Focuses on the reading and mathematical skills of students in the early grades.	Aims to assess the learning achievements of pupils in French-speaking countries in sub-Saharan Africa.
Scope	Used at school and classroom level	Is a national and international assessment
Content	EGRA assesses reading comprehension and fluency. EGMA measures fundamental mathematical skills	Assesses skills in reading, mathematics and science
Frequency	Periodically throughout the year	Every 3 to 5 years

Fig. 2. The EGRA vs PASEC

ity standards. Many African countries, particularly French-speaking countries, lack national learning assessment policies that meet quality standards. Most assessment tools are time-consuming and require a large workforce, which entails considerable costs. Technological tools are increasingly used to ensure the consistency and availability of data. These include tools such as TANGERINE, which is also very costly to implement, requiring approximately as many tablets as students to be truly effective. This financial reality represents a major problem on a large scale for many countries, particularly those facing budgetary constraints. Consequently, this hampers the regularity of skills and learning assessments.

The insufficient quality of assessment programs and the lack of in-depth data analysis (which could be offered by Machine Learning algorithms) are, therefore, clearly among the key factors that most often hinder the use of assessment data. There is also:

- Lack of guidelines on organizing the data from learning assessments to be useful to teachers, decision-makers, and other stakeholders.
- The time taken to make results available to the public varies, from 06 months to over 03 years (Cabo-Verde, Eswatini)[12], but is on average within a year of the assessment taking place. It is, therefore, virtually impossible to use the results at the school level to help improve learning outcomes during the school year.

Learning outcomes cannot be improved without rigorous systems capable of generating the required learning data. It is, therefore, necessary to make systemic use of learning assessment data to evaluate interventions and reforms, plan remedies, and allocate resources accordingly.

2.2 Learning of African languages

In addition to the well-known challenges for French and English, natural language processing on African languages raises new challenges such as linguistic distance from Indo-European languages (alphabet, intonation, accentuation, grammar, syntax, context, ...), dialect diversity (some languages have more than 20 derived dialects), code-switching (using more than one language in a single conversation), endogenous concepts (oral characteristics generally reflect the speaker's way of thinking, as much as the choice of words).

Analyzing the strategy document for teaching Cameroonian languages and cultures, we find that training is essentially based on oral and reading skills. Language acquisition assessment is based on fluency, intonation, coherence, vocabulary, conjugation, and grammar. There are more than 200 national languages in Cameroon, belonging to different linguistic families. A study carried out between 1960 and 2005 found that 85 (out of 200) national languages were mentioned by the people surveyed as the languages in which they had become literate [11]. The actual school environment is such that it is very difficult to implement this assessment. Indeed, in a classroom, we have an average of one teacher to 40- 60 students. The teacher speaks and understands no more than three languages;

on the other hand, there are more than seven different languages spoken by the students. Furthermore, even when concentrating on the same language, students have different levels of reading deficiencies. In the same class, you can have students who can't identify graphemes, while others have difficulty with invented words and others with reading/listening comprehension. This calls for an automatic speech assessment solution. By embedding as many languages as possible, such a solution will enable teachers to assess (and train) each student in his or her mother tongue and improve training time in this area. Natural Language Processing (NLP) is the most suitable AI approach to build such a solution.

They are working to use AI to produce books in Bambara [16]. NLP combines computational linguistics—rule-based modeling of human language—with statistical and machine learning models to enable computers and digital devices to recognize, understand, and generate text and speech. It covers various applications such as machine translation, sentiment analysis, automatic correction, and automatic speech recognition;... Ambiguity, synonymy, and coreference are some challenges NLP models have to overcome to extract useful information and knowledge from text and speech.

Thus, AI models should be developed with sensitivity to the nuances and cultural context, i.e., active involvement of African languages speakers is challenging to ensure that the generated models are culturally appropriate. Moreover, all the African languages are low-resourced, i.e., languages with relatively less data available (lack of annotated text, speech data, or other linguistic resources) for training AI systems. With or without the right teaching tools for learning African languages, the quality of learning is intimately linked to the quality of the skills assessment approach.

We focus specifically on using artificial intelligence to improve the learning of African languages. This is an increasingly important theme in the education systems of African countries, and AI is a technology that can facilitate this learning by boosting assessment methods, which are currently very arduous. The use of AI that we present in this paper is part of implementing a new approach to personalized basic skills assessment that we are proposing.

3 Using AI for Systemic Early Grade Reading Assessment

3.1 Context: Cameroon

Cameroon's primary school system has three levels: Level 1: Initiation cycle SIL-CP, Level 2: Fundamental learning cycle CE1-CE2, and Level 3: Advanced cycle CM1-CM2. Among the end-of-level expectations, those related to oral expression are as follows: think and communicate in your native language (for level 1), express oneself orally, fluently, and correctly, and read words and sentences in each student's native language (for levels 2 and 3). The metrics defined to assess students are the following. For levels 1 and 2: relevant vocabulary, accuracy of conjugation, fluency of reading, and respect for speaking time. For level 3:

fluency of expression and intonation, correct and coherent sentence production, respect for grammatical rules, and vocabulary appropriate to the communication situation (see Fig. 3 for more details).

Indeed, if students are not properly assessed, then asserting that a student can or cannot read has no real value. And if detecting the personal shortcomings that mean that each child cannot read is only possible at the end of the year: once again, there is no real added value. In the next section, we describe a new task-related deficiency-based protocol for assessment in primary education. This method seems to us to be more effective than conventional methods. Our ongoing experiments, presented in Section 3.4, are designed to evaluate the proposed method.

3.2 A new framework for reading assessment in primary education: concepts & method

We are interested in teaching at the Right Level methodology. This personalized approach adapts to the level of each student, ensuring that they progress at their own pace and achieve the skills they need to succeed in their education and future lives[15]. To help students acquire fundamental skills quickly, our approach is based on the following two steps:

1. To avoid ambiguity, **clarify what is meant by 'knowing how to read'**. The Fig. 3, specifies the 06 clear tasks to be assessed timed and the metrics to be considered to determine whether a student knows how to read. These tasks are ranked from the most basic to the most complex. The Fig. 3 is inspired by the EGRA/EGMA structure. The metrics for assessing the reading skills and classifying students ("*Not acquired*", "*In process*" and "*Acquired*") have been adapted according to local dynamics, experience/expertise, and the needs of the students.
2. **Group students by level of task-related deficiency in reading** instead of grouping them according to conventional criteria. These conventional criteria include the class where they enrolled at the start of the school year and the age group, etc.

3.3 Data-driven assessment and remediation architecture

Our approach is an iterative process implemented in schools as described in Fig4. In other words, it is a "test-intervene-test again" approach[13], which makes recommendations on how learning outcomes can be improved thanks to the use of prior learning assessment data. It works as follows:

1. **EGRA Initial Assessment:** Students are assessed individually to determine their respective reading proficiency levels. Each student is given a set of precise, timed tasks to do this (see Fig3). This assessment makes it possible to determine precisely where each student falls short concerning each basic task. Based on their results on each specific reading task, students are classified into three categories: "*Acquired*" if the assessment result is at least 85%

N°	Tasks	Skills assessed	Mastery of the skill
1	Letter names & sounds	- Alphabetic knowledge	- Say the names or sounds of the letters. <i>At least 22 letters correctly read per minute</i>
2	Familiar words	- Recognition of written words. - Fluency of recognition	- Read aloud a list of common words. - Read these words aloud fluently. <i>At least 44 words correctly read per minute</i>
3	Invented words	- Decoding ability - Decoding fluency	- Use grapheme-phoneme correspondences to read. - Read aloud fluently <i>At least 44 words correctly read per minute</i>
4	Reading text	- Fluency in reading words in context	- Read text aloud fluently
5	Reading comprehension	- Comprehension of written language	- Correctly answer questions about a text read by the pupil him/herself (textual and inferential) <i>At least 4 questions correctly answered</i>
6	Listening comprehension	- Oral language comprehension	- Answer questions correctly about a text read by the examiner (textual and inferential). <i>At least 4 questions correctly answered</i>

Fig. 3. What is "Knowing how to read?"

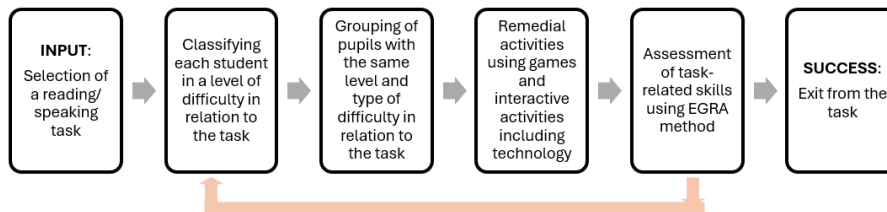


Fig. 4. CAYSTI⁵ approach of reading skills assessment criteria

of the maximum result; "In progress" if the assessment result is between 50% and 84% of the maximum result, "*Not acquired*": if the assessment result is less than 50% of the maximum result.

2. **Grouping by gap level:** At the end of the assessment, students are grouped by gap level for each task. This allows teaching to be tailored to individual needs. The level of students in a group is homogeneous for the concerned task. In other words, a student may be in group Y according to his/her result on the letter sound identification task and in group X according to his/her level on the level 2 addition task.
3. **Targeted teaching:** Within a group, teaching and activities focus on developing the fundamental skill associated with that group (e.g. identifying letter sounds). Here, highly interactive, fun, and techno-pedagogical methods are used to help students progress.
4. **Adapted materials:** Teaching resources are personalized for each group of students. This may include games, books, practical exercises, and outdoor group activities, computer-assisted activities, etc.
5. **Systematic assessment or monitoring and adjustment:** Within the group, students' progress is regularly assessed, and teaching is adapted accordingly, as shown in Fig. 4.
 - If a student makes rapid progress, they can be moved to a higher task group. For example, if the assessment shows that the student can correctly read more than 44 made-up words in 1 minute, they can be moved to a group linked to the listening comprehension task.
 - If students need more support, they can receive extra attention by remaining in their task group. If difficulties persist beyond the time limit and re-personalization, the student's profile is notified to the administration for special attention (Example of dyslexia assessment).
6. **Validation of the pretest tools and implementation:** this crucial stage is also completed thanks to the support of the key players in the educational chain in validating the content and the methodology for administering the pretests, providing the necessary space, and implementing the system. It includes native language speakers, pedagogical inspectors from the Ministry of Basic Education, and techno-pedagogues.
7. **Active participation and reinforcement of teachers through "learning by doing".** The schools' management agreed to provide teachers per site who are fully involved in running the activities. They are assistants in the activities and learn by doing from the team of techno-pedagogues deployed full-time at their site.

This generic framework can be used in many situations and for diverse competencies assessment without important changes.

3.4 Results

The implementation of the proposed framework for reading assessment (French and English) in primary education started six months ago with 02 sites as a

pilot project implemented by the company CASYTI ⁶ involving the Ministry of Basic Education of Cameroon, UNICEF Bureau of Cameroon, the Department of Computer Science of Faculty of Science of the University of Yaounde I. Several evaluations have already been conducted, and the preliminary results are promising. During the pilot phase, the basic reading skills of 800 level 2 primary school students were assessed. At the end of this assessment of reading skills, 80% (i.e., 640 students) were classified as *"Not Acquired"* and enrolled in the pilot phase activities. The 640 students were enrolled in an iterative process as described in Fig4 and personalized according to their level of deficiency linked to each task in Fig. 3. For each task, a series of activities are carried out over a set time to ensure that students with gaps in their skills on the task in question are brought up to speed. Daily and weekly assessments are carried out and captured using an Excel spreadsheet. This database, fed daily, also considers elements such as attendance, observations of emotional state, and desegregated assessment elements. For example, instead of saying that the student can read 20 letters of the alphabet, the level of detail will go down to the list of letters that the student can read to see whether he or she has a problem with vowels and consonants, for example.

Thanks to this database built up over 06 months, machine learning tools are used to:

1. Determine the average number of hours of activity required to enable a regular to move from the *"Not Acquired"* category to the *"In progress"* category for a specific reading task.
We also determine a direct link between absenteeism rates and the level of reading skill acquisition. Fig 5 shows (left) the results of the pre-test, and (right) the results of the post-test after 06 months for a specific reading task (identification of letter sounds). It shows the level of progress according to the number of absences. We can say that after 03 consecutive absences, the probability of remaining in the *"Not acquired"* category doubles.
2. Determine the average number of hours of activity required to enable a regular to move from the *"Not Acquired"* category to the *"In progress"* category for a specific reading task.
3. Predict students' results in writing and mathematics. Our protocol enabled us to establish a strong correlation a) Between reading tasks and b) Between reading and writing tasks (see Fig6). The data of this pilot confirm that children who cannot read (classified in the *"Not Acquired"* category) are also systematically classified as *"Not Acquired"* for math skills (assessed with Early Grade Mathematics Assessment methodology).
4. Predict a student's probability of success at the end of this average time based on its demographic profile and school attendance.

For further validation of the proposed framework, we have chosen to implement it to assess the acquisition of reading competencies for the "Reading" and "National Languages and Culture" courses in primary schools in Cameroon. One

⁶ <https://www.caysti.com>

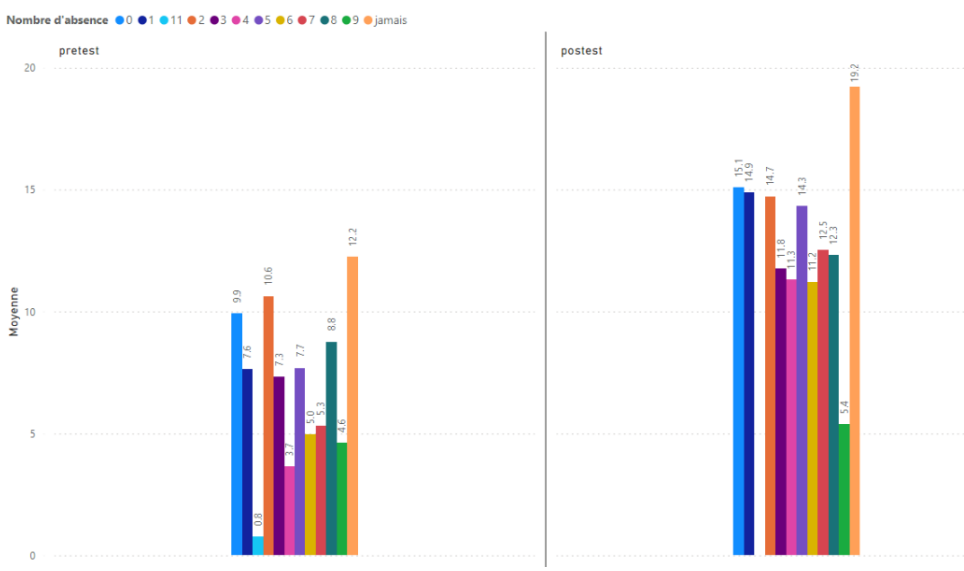


Fig. 5. Correlation between absence and reading skills acquisition"

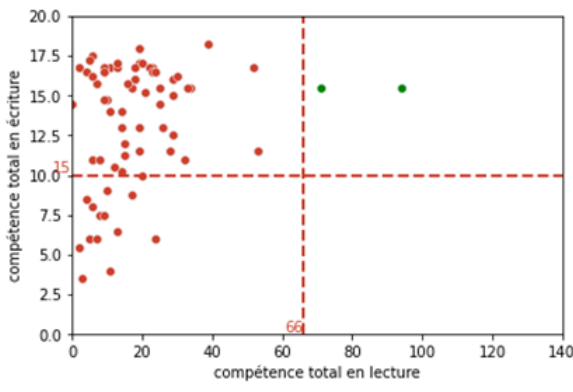


Fig. 6. Correlation between reading and writing skills

language in particular has been selected: Yemba. Details are described in Section 4.2

4 A speech processing approach for assessment for learning African languages

4.1 Context: Yemba

We have already started to collect data in a Cameroonian language, the Yemba, for the proof-of-concept. Yemba is a Niger-Congolese language belonging to the Bantu languages [19], and one of the ten Bamileke languages spoken in Cameroon. It was already spoken by more than 300,000 people in 1992 [20]. As a Niger-Congolese language, Yemba is related to many other languages spoken in sub-Saharan Africa, including Swahili, Lingala, Zulu. Its writing system is based on the Latin alphabet, but has been adapted to include special characters to represent the tones of the language (low, high, and mid) [18].

4.2 A speech processing approach for assessment for Yemba

To implement the proposed framework described in Section 3.3, we must start by instantiating it to assess reading competencies for African languages. The next step will be to create the dataset to train automatic speech recognition models, and the last step will be to design and implement Machine Learning models for the automatic assessment.

The following steps are defined to get the corpus:

1. list the words and expressions in the curriculum that the students need to know in their mother tongue,
2. translate these words and expressions into the Yemba,
3. record pronunciation from students, and build the corpus.

These steps have already been used in a previous work focused on tone recognition [1]. During the first step, we worked with teachers to design the relevant vocabulary for the following points of interest: nature, village, city, school, jobs, travel, health, sport, space, and hobbies. Note that some concepts in this list of points of interest don't exist in Yemba culture. Linguists have translated the dictionary to Yemba using the AGLC (Alphabet Général des Langues Camerounaises) [9]. For the speech recording, the first cohort was made of native speakers of the Yemba language, and to ensure diversity, girls and boys were selected from the three different school levels. Before recording their voices, we explained the experiment's goal to the students and got the formal consent of their school to collect the data and use it for research purposes. The recordings were made in quiet places, depending on the availability of the speakers, in the classroom to capture the natural training environment. The speakers continuously pronounced the words/expressions of the dictionary and were allowed to

correct certain pronunciations and provide repeated versions of words, depending on their availability. The recordings were made using a portable dicta-phone ZOOM H4N PRO HANDY (16-bit resolution and sampling frequency of 44.1 kHz) to reduce electrical background noise due to the collection instrument. The Processing was the same as in [9] with the particularity that the labels, in this case, are the words/expressions in Yemba.

Using the collected data, the next step will be to train Automatic Speech Recognition (ASR) models in the targeted language. According to results from previous research works on low-resourced languages [4–8], we have chosen to :

1. Carry out feature engineering to extract prosody acoustic features such as pitch, energy, duration, and slope of consecutive $F0$. It has been shown that there are important for tonal languages as all the Cameroonian languages [7].
2. Use self-supervised models to generate the embedding of the speech. We have been shown that multilingual self-supervised acoustic models such as wav2vec 2.0 XLSR can perform well for low-resourced languages[4, 5]. Indeed, combining data from different languages during contrastive learning (as wav2vec models) exposes the model to various acoustic and linguistic structures, promoting the emergence of general and shared representations. As a result, the model can learn to extract speech-relevant features from different languages while capturing their similarities and differences.
3. The embeddings are used as the inputs of supervised automatic speech recognition models. Our architecture is the same as [4]: an encoder-decoder architecture where XLSR acts like an encoder and the connectionist temporal classifier (CTC) as a decoder. The XLSR is a multilingual version of wav2vec 2.0 that consists of three parts: 1)the feature encoder, which contains a multilayer Convolutional Neural Network (CNN) to process the raw waveform of audio speech, 2) the transformers to learn a contextualized representation from it, and 3) the quantization module for selecting the speech unit to be learned from the latent representation produced to reduce the size of the representation space.
4. We plan to do data augmentation through a generative model to allow more diversity. Indeed, we have to care about the lack of data to train such high data demand models. Generative Adversarial Networks (GANs), an approach to generative modeling using deep learning methods, such as convolution neural networks, will be used for this purpose. Indeed, GAN uses a supervised approach to learn to generate synthetic examples using two sub-models: the generator model trained to generate new examples and the discriminator model that tries to classify examples as either real (from the domain) or fake (generated). The two models are trained together in a zero-sum game, adversarial until the discriminator model is fooled more than half the time. This approach is of particular relevance when limited data is available.

The data collection on the Yemba language ("National Languages and Culture" part) started 06 months ago, and the pre-processing is ongoing. By the end of this year, we expect to have the first ASR models.

5 Conclusion

African countries are implementing the learning of their local languages in primary and secondary schools to preserve these languages and the culture they support. At the primary education level, the learning is focused on reading (since oral communication is the principal channel for African languages). In addition to the linguistic distance from the dominant languages used in AI (English and French), very few data to train AI models are available for these languages. These characteristics should, therefore, be addressed by developing new AI models. We have described an approach to collect data on the Yemba language and described the architecture of the proposed machine learning process to build ASR models for the assessment of the reading of this language. The tools produced will be integrated into a proposed framework for assessment based on the level of learning task-related deficiency. This assessment approach is supported by machine learning to provide real-time data at the classroom level for instant remediation actions. The framework is generic and can be used in many situations and for diverse competencies assessment. This assessment framework has been tested with French and English reading learning. While the proof-of-concept is ongoing to validate the framework and the data collection for the Yemba language is also ongoing, it would be important to address the question of the transfer of the proposed solution for other basic skills (writing, mathematics, ...) and to other countries and continents.

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