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Different schools for different pupils?

What are the advantages and problems of Luxembourg's highly differentiated and stratified school system?

Thomas Lenz
Christine Schiltz

Executive summary

- The present "Research Note" provides an overview of educational inequalities in Luxembourg and initial approaches to their mitigation.
- Reflecting the complexity of the question, it will analyse this research issue from different disciplinary angles - a social science perspective and a cognitive neurosciences perspective that both are of high importance regarding the question of how to reduce educational inequalities.

Part I. Different schools for different pupils? A social science perspective

- **Social Inequality and Education**. Educational inequality in Luxembourg is shaped by socio-economic status (SES), migration background, and gender, with significant disparities in academic outcomes and school placement. Children from low-SES households face substantial challenges, reflected in lower performance on standardized assessments like the ÉpStan and underrepresentation in the academic Lycée Classique. Migration background further compounds inequality, with Portuguese-speaking students consistently underperforming in German comprehension and being overrepresented in lower academic tracks. Gender disparities also persist, as boys dominate vocational education, while girls are underrepresented in STEM fields, illustrating the multifaceted nature of educational disadvantage.
- The Luxembourgish education system struggles to equally promote all talented students, with socioeconomic status and migration background significantly influencing academic success. Initiatives like European Public Schools (EPS), the "Zesumme Wuessen!" literacy project, and expanded Early Childhood Education and Care (ECEC) aim to ad-

dress these inequalities, showing promise in improving outcomes for disadvantaged groups. However, challenges persist, particularly with transitions between EPS and the traditional system, as well as language-related hurdles for non-Luxembourgish-speaking students. Introducing German in early childhood education and expanding French literacy options may help reduce disparities, but questions about long-term impacts on academic trajectories and social cohesion remain unresolved.

- **European Public Schools.** European Public Schools (EPS) were introduced in Luxembourg in 2016 to address the growing linguistic and cultural diversity among students, offering instruction in German, French, and English with compulsory Luxembourgish classes. EPS students tend to come from higher socioeconomic backgrounds than those in schools following the Luxembourgish curriculum, and they generally perform better in mathematics, particularly among those with migration or French-speaking backgrounds, though performance varies by subgroup. EPS's comprehensive model, which avoids ability tracking, supports continuity in education appears better suited to the multilingual and diverse student population, reducing academic delays and fostering retention. However, challenges remain, particularly for students transitioning out of EPS into schools with the Luxembourg curriculum, where mismatched linguistic preparation can hinder progress, highlighting the need for stronger support systems.
- **Literacy acquisition in French or German.** The "Zesumme Wuessen!" pilot project in Luxembourg allows C2.1 students to begin literacy acquisition in either French or German, aiming to address linguistic diversity and reduce educational inequalities. Initial findings suggest the project may help tackle disparities, with ALPHA-French students showing higher literacy scores and greater motivation in French compared to their ALPHA-German peers, though methodological constraints warrant cautious interpretation.
- **Early Childhood Education and Care.** Early Childhood Education and Care (ECEC) in Luxembourg shows potential for addressing educational inequalities, particularly for children who do not speak the instructional languages at home, but its impact on learning outcomes remains modest compared to family background influences. The LUCET study highlights the need to improve ECEC quality and reassess language policy alignment between early education and later schooling stages, as children from non-Luxembourgish-speaking households struggle with both Luxembourgish and German comprehension. Despite claims that exposure to Luxembourgish prepares children for learning German, findings indicate that linguistic skill transfer between these languages is limited, leaving non-Luxembourgish-speaking pupils at a disadvantage in later literacy development.

Part II. Different schools for different pupils? A cognitive neuroscience perspective

- **Influence of Multilingualism on Math Learning.** Multilingualism can impact math learning due to language switching costs and the need to inhibit non-relevant languages, potentially leading to academic difficulties when the language of instruction differs from the home language as it is the case for about two-thirds of pupils in Luxembourg. Additionally, the lexical structure of languages affects number processing, with German-speaking children being slower due to the inversion of tens and units, and French-speaking children struggling with the vigesimal structure of numbers between 70 and 100.
- **Math achievement in L1 vs. L2 students – Insights from PISA and Épreuves Standardisées.** PISA results show that L2 students (not speaking the language of instruction at home) in Luxembourg score lower in mathematics compared to L1 students (speaking the language of instruction at home), even after accounting for socio-economic and migration backgrounds. These findings highlight the need for targeted educational interventions and monitoring. ÉpStan data reveals that L2 students consistently score lower in math, with the gap widening from grade 3 to grade 9, and even from grade 1 to grade 3,

likely due to the switch from Luxembourgish to German as the language of instruction. German reading comprehension significantly impacts math proficiency, and when German reading skills are statistically equalized, the math disadvantage for L2 students disappears, suggesting that improving German reading skills could help. Additionally, language background affects the identification of math learning difficulties, with Luxembourgish-German children being under-identified and other language groups, like Portuguese, being over-identified, emphasizing the importance of considering language profiles in diagnostics.

- **Arithmetic problem solving and number transcoding in LM1 (Ge) vs. LM2 (Fr) – Insights from experiments.** Behavioural experiments show that adolescents and young adults in Luxembourg solve simple arithmetic problems slightly faster in German (first language of math learning, LM1) than in French (second language of math learning, LM2), with complex problems being completed more quickly and accurately in German. Neuroimaging experiments in young adults reveal that different brain regions are activated depending on the language used, with complex arithmetic problems in French involving additional brain regions for visual processing, indicating higher cognitive effort. Proficiency in number transcoding also varies based on language status, with sequential bilinguals being slower at naming numbers in French (LM2) than in German (LM1) in Luxembourgish schools. The first language of instruction in mathematics significantly impacts learning, and changing the language of instruction at a given moment in the school curriculum (i.e. in grade 7) can lead to slowdowns and errors.
- **Meaning and memorisation of numerals in L(M)2 vs. L(M)1:** A priming study with adult bilinguals showed that one-digit number representations are better in LM1 (German) than in LM2 (French). Additionally, a large-scale experiment found that L2 pupils had a smaller memory span than L1 pupils in a digit-span task using Luxembourgish numbers, but not in a test using language-neutral non-words. Accordingly, language-neutral non-words are now being used to evaluate short-term memory in 6th graders in Luxembourg.
- **Suggestions to enhance math learning in a multilingual context:** To enhance math learning in a multilingual context, it might be advisable to foster the acquisition of the language of instruction (especially in L2 pupils), promote continuity in language instruction, address the additional cognitive effort required when switching languages, and develop language-neutral interventions. Tailor-made diagnostic tools are also necessary and are currently being developed to accurately identify special education needs in multilingual environments.

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Auteurs :

Dr. Thomas Lenz – University of Luxembourg

Prof. Christine Schiltz - University of Luxembourg

Relecteur : Prof. Dr. Andreas Hadjar, Universität Freiburg (Schweiz)

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1 – Introduction

The present "Research Note" provides an overview of educational inequalities in Luxembourg and initial approaches to their mitigation. Reflecting the complexity of the question, it will analyse this research issue from different disciplinary angles - a social science perspective and a cognitive neurosciences perspective that both are of high importance regarding the question of how to reduce educational inequalities.

The first part primarily references recent research findings published as part of the Luxembourg Education Report and various studies conducted by the Luxembourg Centre for Educational Testing (LUCET). Dr Lenz particularly draws on the arguments and findings from an article on social inequality and education by Dr. Susanne Backes and himself, which was published in the book “Bildungs(un)gerechtigkeit in Luxemburg” in 2024.

This part will adopt a social science perspective to first outline the general diversity of Luxembourg (1.1.), then examine the implications of this diversity for the education system (1.2.) and finally analyze three key reforms of the school system in terms of their effectiveness in reducing educational inequalities (1.3.), leading to some brief conclusions (1.4).

The second part adopts a cognitive neurosciences perspective and builds on the work led by the research team of Prof. Christine Schlitz at the University of Luxembourg (*https://eeglabcns.wixsite.com/schiltzlab*). It focuses on the influence of multilingualism and the high diversity of pupil’s language-profile and given the fundamental importance of mathematics in present STEM-based societies it specifically examines math learning and instruction.

2 – Different schools for different pupils? A social science perspective

2.1 – Diversity in Luxembourg

2.1.1 – Nationalities in Luxembourg

Foreigners make up 47.3% of the total population, highlighting the nation's diverse demographic landscape. In 2024, Luxembourg hosts 317,678 foreign nationals, with 12.4% born in the country.

Luxembourg residents represent approximately 180 nationalities. Over three-quarters of the foreign population (245,548 individuals) are citizens of EU-27 countries, while the largest non-EU group consists of 5,357 Ukrainians. The Portuguese community remains the largest foreign group, comprising 13.5% of the total population.

The proportion of foreign nationals in Luxembourg has grown from 26.3% in 1981 to 47.3% in 2024. Portuguese nationals represent 28.6% of all foreigners, maintaining their position as the largest foreign community, though their share has declined slightly in recent years.

Meanwhile, the representation of Italians among the foreign population has dropped significantly, from 23.2% in 1981 to 7.9% in 2024. Similarly, the shares of Germans and Belgians have decreased. In contrast, residents from other nationalities have seen a substantial rise, increasing from 11.1% in 1981 to 35.8% in 2024 (Klein & Peltier, 2024).

2.1.2 – Language Distribution in Luxembourg

Luxembourgish remains the most commonly spoken primary language, identified by approximately half of the respondents in the census. However, while the absolute number of speakers increased slightly from 265,731 to 275,361, its relative share within the population has declined significantly, from 55.8% to 48.9% (Klein & Peltier, 2024).

Portuguese ranks as the second most reported primary language, followed by Italian. Both languages have seen minor decreases in their prevalence among the population.

The use of French and English as primary languages has exhibited a notable upward trend, reflecting their increasing importance in the linguistic landscape of Luxembourg, while German is losing importance as the primary spoken language.

The category "other languages" has experienced the most significant growth, with the number of respondents identifying with this category increasing from 40,042 to 60,582. This rise underscores a growing linguistic diversity and the presence of a more multilingual population.

The linguistic profile of Luxembourg is undergoing significant changes, marked by a declining dominance of Luxembourgish and a growing prevalence of other languages, particularly French, English, and "other languages." These trends highlight the increasing multicultural and multilingual character of the population (Klein & Peltier, 2024).

2.2 – Diversity and Educational Inequality[1]

2.2.1 – Individual and Societal Perspectives on Inequality

Inequality in education can be observed both from an individual and a societal perspective. On an individual level, a low level of individual education is often associated with fewer opportunities in the labour market, lower income, poorer health and lower life expectancy. On a societal level, systematic disadvantages for certain groups prevent the full utilization of existing talents and the associated economic potential. Educational inequality, thus, has far-reaching implications beyond individual outcomes, affecting broader social and economic development.

2.2.2 – Defining Educational Inequality

Educational inequalities are systematic differences in various aspects of educational attainment and success that are structured along certain characteristics such as social origin and migration background (Hadjar et al., 2018).

In educational research, social origin, migration background, gender or, for example, region of residence are very often analysed as characteristics or axes of inequality. Educational success can manifest itself in different aspects, which are referred to as inequality dimensions - the dimensions in which pupils perform better or worse. These are school grades, competency tests, but also aspects such as grade repetition, early withdrawal from the school system and the like.

2.2.3 – Contextual Framework: Demographics, Economy and Social Inequality

In order to be able to analyse the realities and developments in the education system, the education system must be seen in its context. Issues such as demographics, the economy and labour market, poverty and social inequality are key framework conditions in which educational processes take place.

Luxembourg has been experiencing high population growth for many years, with an increase of 44% within two decades (Statec, 2021). The proportion of Luxembourg residents with Luxembourgish nationality has fallen from 63% in 2001 to 52,7% in 2023 (Bildungsbericht Luxemburg, 2024) and Luxembourgish was the main language of only 48,9% of the inhabitants. This has an impact on the composition of the student body at Luxembourg's schools. In the 2022/23 school year, the proportion of pupils of Luxembourgish nationality was 53.3% in primary school (Cycles 2-4) and 57.5% and 65.4% in lower and upper secondary school respectively (Backes & Lenz, 2024b).

The heterogeneity of the student body, expressed in terms of nationalities and language backgrounds, is increasing from year to year. At the same time, this increasingly heterogeneous student body encounters a trilingual school system with high linguistic demands. **These demands are often too much for children who do not speak any of the three languages of instruction at home.**

Luxembourg's school system is also characterised by a high degree of stratification, i.e. several parallel school types are offered at secondary level, leading to different educational qualifications and career options.

Luxembourg is a prosperous country that has nonetheless seen an increase in the risk of poverty over the past 20 years. The risk of poverty - i.e. the risk of having an income below 60% of the median income of all Luxembourg residents - rose from 12% in 2000 to 17.4% in 2022 (Statec, 2024). The risk of poverty is not the same for all population groups: for example, people of Portuguese nationality have a risk of almost 30%, while people living alone with more than one child have a risk of over 50% (ibid.). As the resources of the parental household are strongly linked to the ed-

[1] Parts of this chapter are from Backes & Lenz, 2024a.

ucational success of pupils, as explained above, it can be assumed that this social inequality is also reflected in schools.

2.2.4 – Key Axes of Educational Inequality in Luxembourg

Socio-economic status (SES), reflecting the social and economic conditions of a family, plays a crucial role in shaping educational inequality, particularly in Luxembourg. SES is commonly measured through parental factors such as occupation, educational level, and income.

Studies consistently show that children from low-SES households experience significant challenges in achieving favourable educational outcomes compared to their peers from higher-SES families.

Standardized assessments, such as the ÉpStan, have consistently highlighted pronounced performance gaps between low and high SES students. Considering the socio-economic background, the ÉpStan show that socially disadvantaged children start with a similar, albeit slightly lower, baseline at the beginning of their school careers in C2.1 compared to their socially advantaged peers. However, by C4.1 (just before the transition to a different school track), socially disadvantaged children are significantly less likely to reach the "Socle" or "Avancé" levels. Specifically, at the beginning of C4.1, 52% of socially advantaged children achieve the "Avancé" level, while only 15% of their socially disadvantaged peers do. Additionally, 51% of socially disadvantaged children fail to reach the "Socle" level, compared to just 18% of socially advantaged children falling below this minimum level in Cycle 4.1. (Ottenbacher et al., 2024). These disparities persist into secondary education, where students from low SES households underperform relative to those from advantaged backgrounds in key academic areas (*ibid*.).

One of the most persistent manifestations of SES-related inequality is its influence on secondary school placement.

Children from low SES households are significantly underrepresented in the academic Lycée Classique (ESC), a pathway associated with higher educational and career prospects.

Data from the 2022/23 academic year reveal that **only 14,2% of children from low SES households were directed to the Lycée Classique, compared to 70,4% of children from high SES households**. At the same time, 19.9% of children from disadvantaged households were directed to the "Voie de préparation," whereas only 3.4% of children from higher-income households were placed in this track. (Backes & Hadjar, 2024).

Another axis of educational inequality in Luxembourg is the migration background of students, which is closely linked to their home language and nationality.

For example, in Cycle 3.1, the German listening comprehension scores of Luxembourgish/German-speaking children exceed those of Portuguese-speaking children by 119 ÉpStan points, with the gap widening to 142 points for German reading comprehension (Fischbach, Colling et al., 2021).

A comparative analysis of PISA (Programme for International Student Assessment) results for 15-year-olds underscores these disparities: Portuguese-speaking adolescents in Luxembourg achieve lower scores than their counterparts in Switzerland, even when parental education levels are comparable. (Chauvel & Schiele, 2021).

Migration background also influences secondary school placement. Portuguese nationals are significantly underrepresented in the lower grades of the highest academic track (ESC) at just 7.7% and overrepresented in the lowest academic track (ESG-VP) at 41.4%. In contrast, Portuguese students make up 22.5% of the overall student population in the lower grades of the secondary school system (Backes & Lenz, 2021).

Luxembourgish students show the opposite trend: they are overrepresented in the ESC (68.7%) and underrepresented in the ESG-VP

(37.6%), even though they comprise 57.1% of the total student population.

Gender-based patterns in school tracks and career choices are pronounced.

Boys are overrepresented in vocational education tracks, such as Régime Professionnel making up 62.6% of students compared to 37.4% for girls (Backes & Lenz, 2021) and girls are overrepresented in the academic track (classique). Similarly, gender imbalances persist in higher education, where women are notably underrepresented in STEM[2] fields, accounting for only 31.2% of students in these areas (Gewinner et al., 2021).

These axes of inequality are interconnected. For example, boys from working-class families with migration backgrounds in urban areas are particularly vulnerable to educational disadvantage due to the interplay of these factors.

2.3 – Responses to Educational Inequality in Luxembourg and their impact

2.3.1 – European Public Schools (EPS)[3]

2.3.1.1 – Development and Objectives of EPS

As mentioned before, the student population has become increasingly diverse, particularly concerning linguistic backgrounds. This development has been addressed, among other measures, through an adaptation of the school offerings. **Of particular importance are the international educational programs, especially the (currently six) European Public Schools (EPS), which have been gradually integrated into the national education system since 2016.** The opening of three additional EPS is planned.

The EPS are intended to take better account of the country's diversity and multilingualism. They function in a similar way to the two European Schools I and II set up in Luxembourg in 1953 and 2004, which were founded and financed by the governments of the EU member states). The EPS offer German, French and English language sections. This allows pupils to choose the language of instruction from these three languages that corresponds to their first language or is most closely related to the language they use at home. In addition, Luxembourgish is a compulsory subject for all pupils.

Since the first EPS (EIDE – *Ecole internationale de Differdange et d'Esch-sur-Alzette*) was set up in 2016, five more have been opened, meaning that the proportion of pupils in EPS programmes has risen from 0.2% to 3.9% in primary schools and from 0.2% to 5.7% in secondary schools.

2.3.1.2 – Nationality, Language and Socio-economic Status of Students in EPS

Portuguese pupils make up the largest group of foreign nationals in schools with the Luxembourg curriculum (15.3% in primary and 18.9% in secondary education), **while non-EU pupils make up the largest group in the EPS** (26.6% in primary and 22.6% in secondary education), followed by French pupils in primary education (20.6%) and Portuguese pupils in secondary education (14.4%).

Accordingly, French (43.8 %) was the language most frequently spoken at home by pupils enrolled in EPS, while in the Luxembourgish curriculum it was Luxembourgish (45.2 %). The situation is similar with regard to the language spoken predominantly at home by pupils at secondary level. 39.0 % speak Luxembourgish predominantly in the Luxembourgish curriculum, while the largest proportion (26.3 %) speak French predominantly in the European curriculum.

The socio-economic status of pupils in EPS at primary level is higher (with a mean HISEI[4] value of 59.4) **than that of pupils in the Luxembourgish curriculum** (50.3). The same is true

[2] Science, Technology, Engineering, Mathematics.

[3] Cf.: LUCET & SCRIPT (Eds.). (2023). European Public School Report 2023: Preliminary Results on Student Population, Educational Trajectories, Mathematics Achievement, and Stakeholder Perceptions.

[4] The International Socio-Economic Index of Occupational Status combines income and education to reflect the status of an occupation. The lowest value of the index is 16 (e.g., unskilled workers) and the highest 90.

for secondary level, where the HISEI value averaged over all pupils in EPS (55.7) is higher than the average value of all pupils in schools with the Luxembourgish curriculum (44.9). However, if we compare the average HISEI scores in the different school forms of the Luxembourg curriculum (ESC, ESG and ESG-VP), we see that the EPS score is minimally lower than the score of pupils in the academic school form of the Luxembourg curriculum (ESC).

For Schools with a Luxembourgish curriculum, the school with the lowest average family income recorded €25,408, while the highest reached €69,781. In the case of the EPS, the school with the lowest average family income recorded €33,506, and the highest reached €55,969. These figures highlight the income disparities, even within the same curriculum (national vs. European). Particularly for Schools with a Luxembourgish curriculum, these discrepancies can be explained by the generally significant social inequalities between different geographic areas in Luxembourg.

An additional interesting aspect concerning socioeconomic security is Luxembourg's minimum income guarantee (REVIS): The proportion of students living in families receiving REVIS is more than twice as high in Schools with a Luxembourgish curriculum as in EPS within the scope of fundamental education.

2.3.1.3 – Performances of students in EPS

The integration of European Public Schools (EPS) into Luxembourg's School Monitoring Programme “Épreuves Standardisées” (ÉpStan) allowed for the analysis of full-cohort data, encompassing primary and secondary school students from the 2022/23 academic year. This analysis aimed to compare EPS students’ mathematics performance with that of their peers in schools following the Luxembourgish curriculum, a subject assumed to have greater overlap between the two systems than language curricula (e.g., German, French).

Analysis of students with specific background characteristics reveals that **both male and female students in EPS achieve higher average scores in mathematics compared to their peers in schools following the Luxembourgish curriculum**.

Within each system, male students outperform female students in mathematics. High SES students perform similarly well in mathematics across both school types, while preliminary findings suggest that low SES students in EPS outperform their counterparts in schools following the Luxembourgish curriculum.

For migration background, no consistent pattern was observed among native students across all three grades. However, EPS students with a migration background show higher average scores in mathematics than their counterparts in schools following the Luxembourgish curriculum. This finding is nuanced by the fact that EPS students with a migration background tend to have a higher SES than their peers with a migration background in Luxembourgish curriculum schools, making it difficult to generalize these results across all migration types and origins.

Regarding language background, French-speaking students in EPS consistently outperform their peers in Luxembourgish curriculum schools across all three grades. Luxembourgish and/or German-speaking EPS students show lower average scores in grades C2.1/P1 and C3.1/P3 but outperform their peers in grade C4.1/P5. Similarly, Portuguese-speaking EPS students perform better in mathematics in grades C2.1/P1 and C4.1/P5, although the difference in grade C3.1/P3 falls within normal variations. English-speaking EPS students also show a comparable pattern of higher achievement.

In summary, these findings at the primary school level indicate that EPS students generally demonstrate better mathematics achievement compared to their peers of the same background and gender in schools following the Luxembourgish curriculum, with variations across specific subgroups.

At the secondary school level, EPS students, on average, performed better in mathematics than students in ESG and ESG-VP but fell behind the performance of ESC students.

The findings are preliminary and subject to methodological constraints, including small sample sizes for specific subgroups (e.g., low SES students in EPS) and the alignment of ÉpStan tasks with the Luxembourgish curriculum, which may disadvantage EPS students. Interpretation is further complicated by structural differences, such as comparing EPS's comprehensive system with the ability-tracked Luxembourgish system.

2.3.1.4 – Preliminary findings

Overall, these results reinforce the conclusion that diversifying the educational offerings could be a way to address existing educational inequalities in Luxembourg.

A possible explanation for the observed performance differences in favour of EPS students could be that **EPS provides a better linguistic match for Luxembourg's linguistically diverse student body.** The language sections in EPS allow students to be taught in a language that corresponds to the one spoken at home or a related language (e.g., another Romance language).

This linguistic adaptability is complemented by the structural design of EPS, which employ a comprehensive school model without tracking. This design fosters greater continuity in students' educational trajectories, characterized by lower levels of academic delays, fewer decision-making and reorientation phases, and higher overall retention rates. Consequently, EPS students experience fewer disruptions in their academic progression compared to their counterparts in Luxembourg public schools.

The combination of linguistic alignment and the comprehensive organizational framework of EPS differentiates them from traditional schools. **These features appear to be better suited to the linguistic and cultural diversity of Luxembourg's student population, offering a more inclusive and adaptable educational model**.

Despite these advantages, emerging challenges have been identified for students who encounter difficulties within the EPS system due to its academic rigor or specialized focus. For such students, transitioning to schools following the Luxembourg curriculum can present significant obstacles. This is particularly evident when the predominant instructional language in the new school (e.g., German in vocational education) does not correspond to the language section chosen by the student in the EPS, nor has it been adequately developed as an additional foreign language.

While EPS provide a distinctive and potentially advantageous model for multilingual education, addressing the challenges faced by students requiring alternative pathways is essential. This necessitates a more robust framework for ensuring linguistic and academic continuity during transitions between EPS and public schools following the Luxembourg curriculum.

2.3.2 – Literacy Acquisition in German or French in Primary Schooling[5]

To address the linguistic diversity of students and reduce educational inequalities linked to a curriculum with high language demands, the Luxembourgish government introduced the literacy pilot project "Zesumme Wuessen!" in four primary schools. This initiative enables C2.1 students to begin literacy acquisition in either French (ALPHA-French) or German (ALPHA-German) within mixed classes.

A report from the Luxembourg Centre for Educational Testing analysed data from the Luxembourg School Monitoring Programme (ÉpStan) collected in autumn 2023, comparing pupils in the ALPHA-French and ALPHA-German groups. While the findings offer valuable insights, **they must be interpreted cautiously due to statistical and methodological constraints**.

Nevertheless, the results provide initial evidence that the pilot project could help address educational inequalities in early primary education. Notably, students in the ALPHA-French group achieved higher scores on literacy assessments in their chosen language and demonstrated greater motivation to learn and read in French compared to their peers learning to read and write in German.

2.3.3 – Early Childhood Education and Care (ECEC)[6]

The LUCET study on ECEC in Luxembourg examined its potential as a preventive measure to address the country's pronounced educational inequalities. Given Luxembourg's high ECEC attendance rates, it shows promise as a means to improve learning outcomes and academic success, particularly for children who do not speak the instructional languages at home.

While the impact of ECEC on learning performance is currently positive but modest compared to the influence of family background factors, the study's authors emphasize the need for policymakers to prioritize improving and monitoring ECEC quality. They also advocate reassessing the alignment of language policies between ECEC and later stages of education.

ÉpStan data indicate that children who speak Luxembourgish at home significantly outperform their peers in basic German listening comprehension, irrespective of socioeconomic background. The Luxembourgish curriculum prioritizes Luxembourgish proficiency in Cycle 1 to prepare students for literacy acquisition in German in Cycle 2, based on the assumed transferability of skills between these linguistically related languages.

However, with nearly 70% of children not speaking Luxembourgish at home, this transferability is limited. Data reveal that children from non-Luxembourgish-speaking households perform poorly in both Luxembourgish and basic German listening comprehension, leading to difficulties in German reading comprehension in later cycles (Cycles 3 and 5).

While Cycle 1 focuses on orally-learning Luxembourgish (the main language of communication in Luxembourg), German is the teaching language for all subjects (except French) in Cycles 2 to 4. French is introduced orally in cycles 1 and 2, and starts to be learned in written from cycle 3 (The Luxembourgish Education System - an Overview 2023, 2024). Although the Luxembourgish Ministry of National Education, Youth and Childhood (MENJE) states that "The exposure to Luxembourgish [which begins at crèche] prepares children for learning German, since the two languages are very closely related" this is not con-

[5] Cf.: Colling, J., Hornung, C., Esch, P., Keller, U., Hellwig, A.-L., & Ugen, S. (2024). Literacy Acquisition in German or French in the Pilot Project "*Zesumme wuessen!*" – Preliminary ÉpStan Results of Student Characteristics, Achievement, Motivation, and Parental Support. Luxembourg Centre for Educational Testing (LUCET).

[6] Cf.: Hornung, C., Kaufmann, L. M., Ottenbacher, M., Weth, C., Wollschläger, R., Ugen, S. & Fischbach, A. (2023). Early childhood education and care in Luxembourg. Attendance and associations with early learning performance. Luxembourg Centre for Educational Testing (LUCET).

firmed by the LUCET report of Hornung and colleagues (Hornung et al., 2023). Indeed, L2 pupils speaking only French or Portuguese at home score significantly lower in German than in Luxembourgish listening comprehension in first grade (Fig. 1). And this result pattern is observed independently of the pupils' socio-economic background. Thus, the expected transfer of language competence in Luxembourgish to German is not achieved.

To address this issue, the study's authors (Hornung et al. 2023) recommend introducing German in Cycle 1. Early exposure to German would better prepare children for its use as the primary instructional language in Cycles 2–4. German comprehension is crucial for success in literacy and mathematics in Cycle 2, as a robust vocabulary and strong listening skills in the instructional language underpin reading development and comprehension.

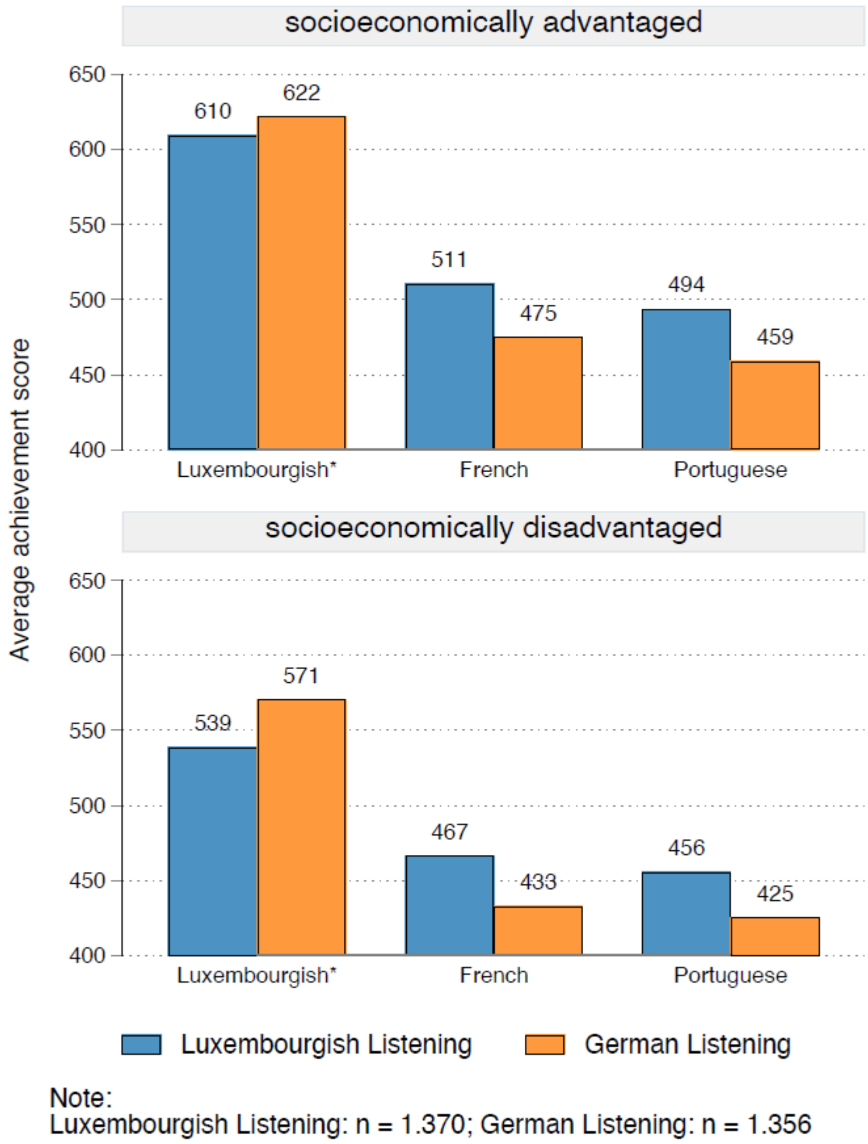

Figure 1. Average achievement score in German and Luxembourgish listening comprehension by socioeconomic status and home language group (ÉpStan data of Luxembourg's first graders 2022) (Fig. 29, p.52 from (Hornung et al., 2023).

2.4 – Conclusion

The Luxembourgish education system does not equally promote all talented students. Many children from socioeconomically disadvantaged families do not attend higher secondary schools, even though they have the necessary cognitive potential to do so.

The education reports from the University of Luxembourg (2015, 2018, 2021, 2024) showed that **the socio-economic status of a family has a significant influence on the educational success of children**. A correlation between migration background and academic success also exists, as children who do not speak one of the three national languages at home must sequentially learn Luxembourgish, German, and French in the education system - an insurmountable obstacle for many.

Luxembourg has implemented various educational initiatives to address its significant educational inequalities, particularly related to linguistic diversity and socioeconomic disparities. Key developments include the establishment of European Public Schools (EPS), the literacy pilot project "Zesumme Wuessen!," and the expansion of Early Childhood Education and Care (ECEC).

EPS's multilingual and comprehensive model has shown promise in improving outcomes, particularly for low SES and migration-background students. The literacy pilot project highlights the benefits of tailored language instruction, while ECEC offers potential as a preventative **measure against early disparities.**

However, the interplay of these reform initiatives is not yet fully clear. In particular, within the EPS, the question of transitions from the traditional system to the EPS and vice versa is challenging. Additionally, for EPS students, the transition to vocational training is less straightforward than for their peers in the traditional system.

In the conventional Luxembourgish education system, **the transition from early childhood education to primary school is challenging for those who do not speak Luxembourgish at home**. They must first learn Luxembourgish as the assumed integration language before being alphabetized in German in primary school. It would be advisable to introduce German in the early childhood education sector as well. Alphabetization in French appears to be a promising reform for certain student groups, with the potential to reduce educational inequalities.

However, **the initial study results are not yet robust enough to make definitive statements on this matter.** Additionally, questions about continuity remain: How do the academic and vocational trajectories of children who were alphabetized in French compared to those of their peers who were alphabetized in German? And what are the medium-term implications of this language choice for the country's social cohesion?

3 – Different schools for different (language-profile) pupils? A cognitive neuroscience perspective

3.1 – Language(s) and numerical and mathematical thinking and learning

3.1.1 – The influence of multilingualism on (math) learning

Since bilinguals have two (or more) languages to communicate with and both languages are always active, the inadequate language must be inhibited by cognitive selection and control mechanisms (Hernandez, 2013). When switching between languages, bilinguals may thus be confronted with Language Switching Costs (LSCs). Short term LSCs can be observed when, following a trial where 5 was named "five", the next digit trial must be named in a second language (Declerck & Philipp, 2015). Long-term LSCs occur during language switching such as between training and testing and have also been observed in relation to mathematical performance (Spelke & Tsivkin, 2001).

Given the continued need to control language coactivation, some authors have also suggested that bilingualism may function as cognitive training, thereby improving executive functions and acting as a neuroprotector (Bialystok et al., 2004a). The cognitive advantage of bilingualism is, however, a controversial notion and may be partly due to publication bias (e.g., (Paap et al., 2024)). On the other hand, **it is well established that second language learners encounter academic difficulties when bilingualism follows schooling with a language of instruction that differs from the language spoken at home**, as is typically the case in migration situations and will be explained in detail below for the situation in Luxembourg (e.g., Beal et al., 2010; Greisen et al., 2021).

3.1.2 – The relevance and importance of mathematics

Mathematics is a fundamental component of school education. The likelihood of securing a full-time job is linked to arithmetic competence, which includes basic arithmetic knowledge and the ability to apply this knowledge to solve everyday problems (Rivera-Batiz, 1992). **Generally, higher achievement in mathematics correlates with greater success in professional life**, such as achieving a higher socio-economic status and better academic qualifications ((Duncan et al., 2007);(Ritchie & Bates, 2013)).

Therefore, it is crucial to understand how mathematics is learned and how it can be most effectively taught. Traditionally, this question has been addressed by educational sciences. However, recent advancements in cognitive (neuro)sciences are providing additional insights, enriching our understanding of learning and teaching in general, and mathematics in particular (Kail & Fayol, 2003;Blakemore & Frith, 2005).

Everyone can manipulate approximate numerical quantities independently of language (Xu & Spelke, 2000). This skill is shared with very young children and even other animal species. However, mastering symbolic representations of exact (large) quantities requires language and instruction (e.g., Pica et al., 2004). **In other words, language facilitates and shapes the learning of exact numerical concepts** (Fuson et al., 1982; Le Corre et al., 2006). Therefore, it is essential to analyse how a given language context influences and shapes numerical and mathematical thinking. This is particularly relevant in a multilingual country like Luxembourg.

3.1.3 – Numbers are processed differently depending on the language used

The lexical structure of the language(s) spoken influences number processing and math (Schiltz et al., 2024).

To understand how the two languages used in the Luxembourg school curriculum (German in basic education and French in secondary education) influence numerical and mathematical thinking, we first need to understand the impact of each of the two languages separately.

To this end, we examined the processing of two-digit numbers in a group of monolingual French- and German-speaking 10-year-old children (n = 42) and young adults (n = 50) (Poncin et al., 2020). While French- and German-speaking adults performed these tasks similarly, German-speaking children were significantly slower than their French-speaking peers. German-speaking fourth graders were thus almost 200ms slower to match heard two-digit numbers with their corresponding visual numeral than their French-speaking peers.

These findings suggest that languages which invert tens and units (referred to as 'inverted' languages, such as German) impose a cognitive cost on children's number processing, although this cost tends to diminish by adulthood.

Likewise, certain characteristics of French mathematical vocabulary are particularly difficult to master. **Our studies on monolingual pupils indicate that the vigesimal structure of French number words between 70 and 100 (e.g., 72 = 'soixante-douze') creates difficulties in processing these numbers** (Van Rinsveld & Schiltz, 2016). By comparing 4th-grade children in English and French primary schools in Luxembourg, we found that French-speaking children were slower and more error-prone in auditory-visual matching and reading of number words above 60 compared to English-speaking children, who use a decimal structure (e.g., 72 = 'seventy-two').

Based on these observations, we might consider introducing educational measures specifically aimed at these linguistic difficulties, enabling young children to identify and tackle them effectively. Intervention studies targeting the inversion in German and the vigesimal number word construction in French would be needed to validate tailor-made educational interventions.

3.2 – How language influences number processing and math in the multilingual education system in Luxembourg

3.2.1 – Math achievement in L1 vs. L2 students - Insights from PISA

The Programme for International Student Assessment (PISA) of the OECD aims to evaluate the cumulative outcomes of education and learning at a point when most young people are still enrolled in formal education. It targets 15-year-old students in over 85 countries worldwide. This age group is chosen to provide a consistent basis for comparison across different countries and education systems. The last PISA assessment in Luxembourg was conducted in 2018. Luxembourg did not participate in the PISA 2022 study, but it will take part in the next PISA study in 2025.

PISA assesses student's competences in reading, math and sciences. The results are described overall for each participating country, but also more specifically for different subgroups of students. Groups can for instance be made based on students' language spoken at home, their migration background, or their socio-economic background. These factors are often linked, which is also strongly the case in Luxembourg. Using statistical approaches, it is nevertheless possible to consider the influence of each variable after correcting for the influence of the others.

In the PISA report 2016 it appears thus that in Luxembourg being an L2 student (i.e., not speaking Luxembourgish or German at home) accounts for a loss of 24 points on the PISA scale, independently of a student's migration and socio-economical background (Fig. 3).

This is a striking result, given that a difference of 20 points on the PISA scale is generally considered to be equivalent to about half a year of schooling (oecd.ilibrary.org). While these specific analyses are not described for math in the 2018 report (Pisa rapport, 2018), overall result trends remain the same. Given the increasing number of L2 pupils, it will be crucial to monitor the upcoming results of the Pisa 2025 assessment with respect to the language spoken at home.

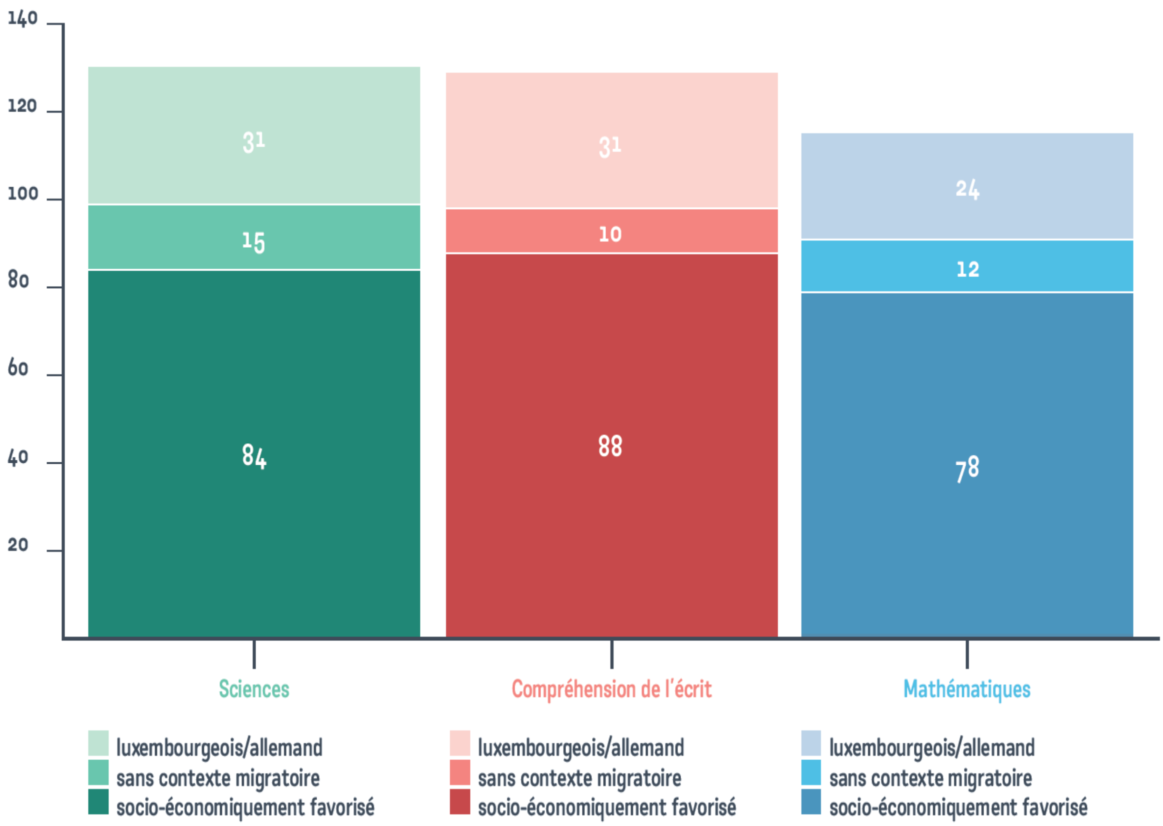

Figure 3. Expected performance differences in sciences, text comprehension and math due to socioeconomic status, migration context and language spoken at home (Figure from p.10 (Pisa rapport, 2015)))

3.2.2 – Math achievement in L1 vs. L2 students - Insights from the "Épreuves Standardisées"

3.2.2.1 – Math achievement is negatively impacted by the L2 status of students

The "Épreuves Standardisées" (ÉpStan) are an instrument of school monitoring and represent an established and standardized measure for assessing the performance of children at the beginning of a learning cycle in the Luxembourg education system (Martin et al., 2014). They provide different competence tests for the grade levels they address. They take place at the beginning of a grade level and aim to evaluate mathematical and language skills of the previous grade.

In figure 4, the link between language background and student competences is explored with the variable “language background” comparing the three most representative language groups in Luxembourg, i.e. Luxembourgish or German, French and Portuguese. Only students who speak the same language with both of their parents and who have been registered with the national school system since pre-school are included in the analyses.

These data indicate that L2 students (i.e., not speaking Luxembourgish or German at home) are consistently achieving lower math scores in all grades since 2018.

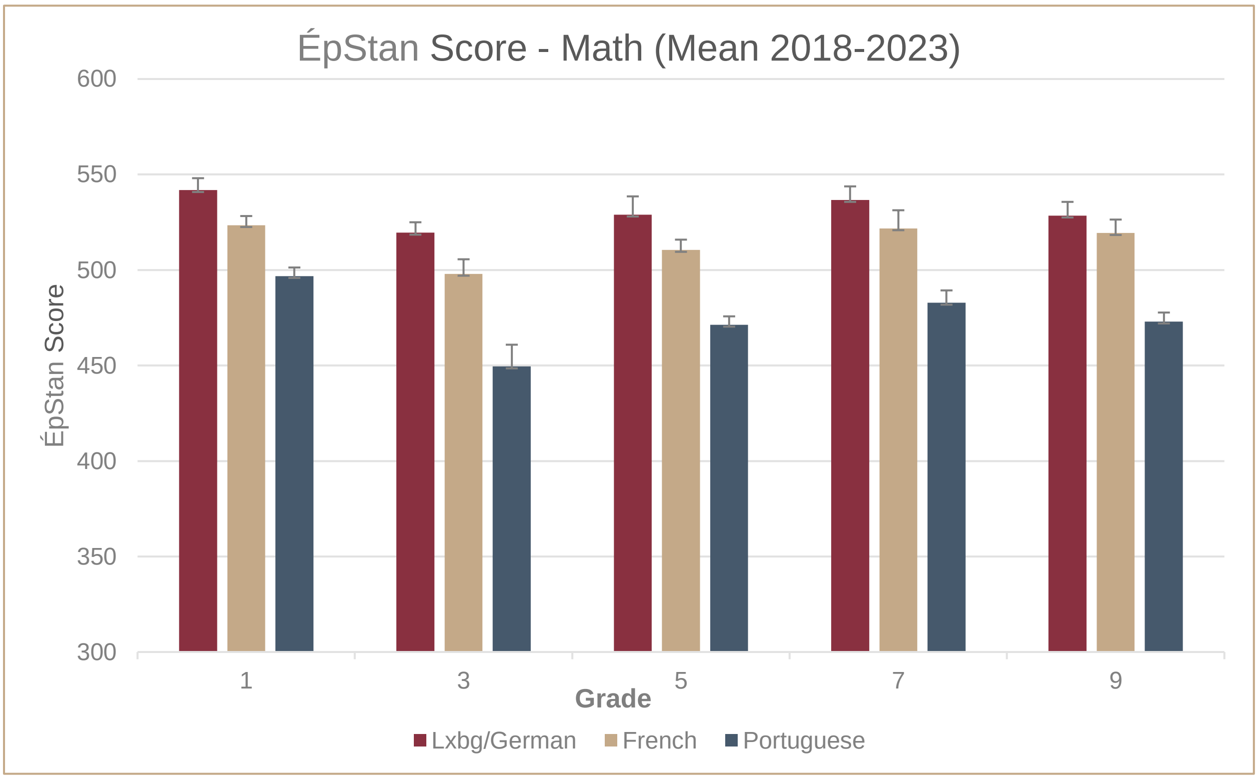

Figure 4. ÉpStan score in math achieved on average over the period from 2018 to 2023 and displayed for the three most representative language groups in Luxembourg, i.e. Luxembourgish or German, French and Portuguese (data from *https://dashboard.epstan.lu/?lang=EN*).

Moreover, when grouping pupils speaking one of the official instruction languages Luxembourgish, German or French and contrasting them with pupils speaking Portuguese from the cohorts 2011-2017, 2012-2018 and 2013-2019 it appears that the language-related differences in math levels are drastically increasing from grade 3 to grade 9 (Sonnleitner et al., 2021). While the percentage of pupils failing to achieve the expected competence level (i.e. “niveau socle”) increases from 12-15% in grade 3 to 33-36% in grade 9 for pupils speaking one of the official instruction languages, the number of Portuguese-speaking pupils performing below the “niveau socle” is twice as large in grade 3 (26-30%) and it increases to a highly alarming two thirds of all Portuguese-speaking pupils in grade 9 (61-66%).

When considering the evolution of math competence from grade 1 to grade 3, similar advantages for children speaking Luxembourgish or German already appear, as they are the only language group which is not characterized by the fact that most children are decreasing their math performance from grade 1 to 3 (Fig. 5). Hornung and colleagues (2021) propose that this negative trend could be explained by the change of the language of instruction from Luxembourgish in Kindergarten to German in Grade 1, which is especially challenging for L2 children (i.e., pupils who are not speaking Luxembourgish) (Hornung et al., 2021).

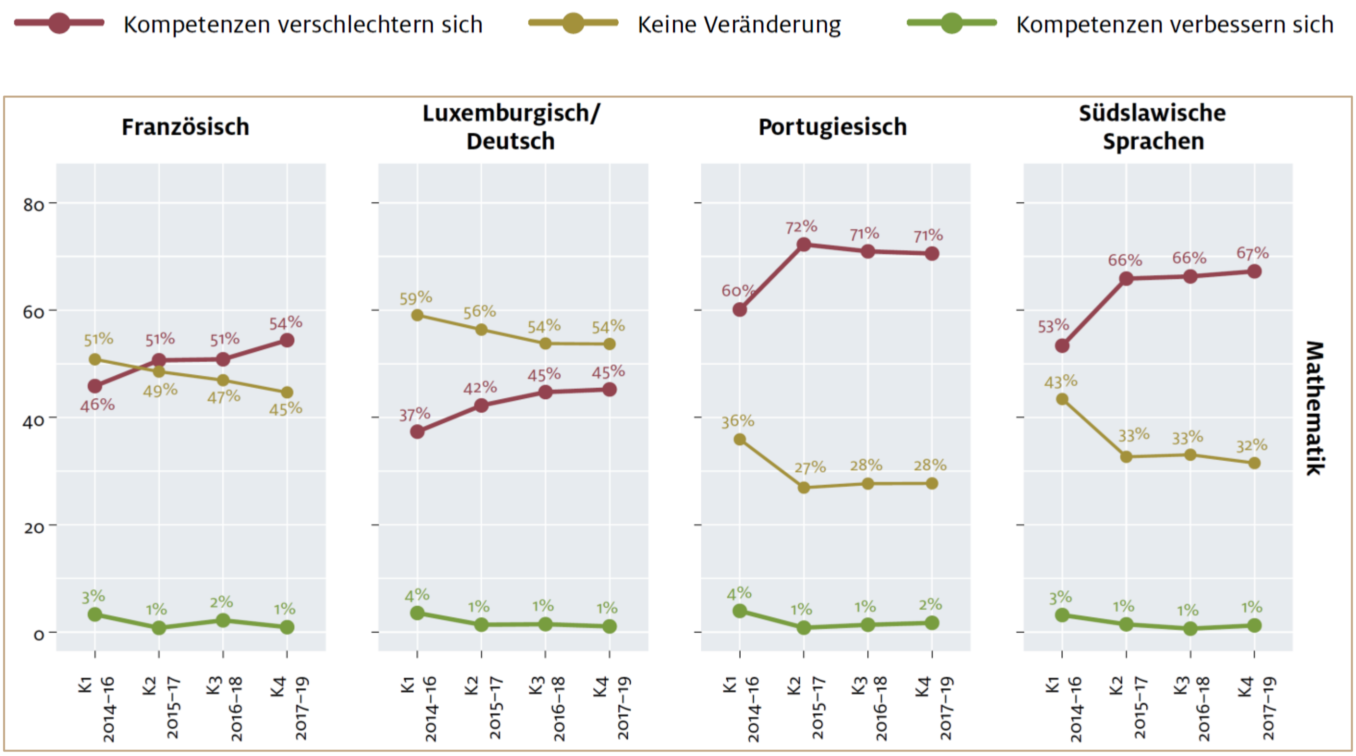

Figure 5. Developmental trajectories from Cycles C2.1 and C3.1 for all four cohorts without delayed school career for mathematics, displayed separately for the four most representative language groups in Luxembourg, i.e. Luxembourgish or German, French, Portuguese and Slavic language. (Figure 2, p.48 from (Hornung et al., 2021))

3.2.2.2 – Low mastery of the instruction language (i.e. German) is a critical factor for low math achievement

Furthermore, a detailed analysis of ÉpStan data of Cycle 3.1 from 2015 and 2016 revealed that math competence achieved in Grade 3 is partially based on mastery of the official instruction language (i.e. German) in Luxembourg (Greisen et al., 2021).

Comprehension in German reading indeed has a direct positive effect on math proficiency. This applies even when statistically accounting for children's home language and their socio-economic status. Children who do not speak Luxembourgish or German at home not only perform worse than Luxembourgish children in German reading but also show a clear disadvantage in math. However, this disadvantage disappears if we statistically equate the knowledge of the German language of instruction of all children. In other words, these analyses reveal that the disadvantages in math of children who do not speak Luxembourgish at home can be directly explained by a weakness in German reading comprehension (mediation analysis) (Figure 6).

Figure 6. *Graphical summary of the influence Comprehension in German reading on math competence achieved in Grade 3 according to the language spoken at home, i.e.* Luxembourgish or German, French, Portuguese (Figure p.14 from the LEARN newsletter 2023, https://learn.uni.lu/wp-content/uploads/newsletter/UL_23_LEARN_NL_LX_EF_online.pdf).

These findings suggest several options to enable every child to achieve optimal mathematical development independently of their language background. **Future studies should examine the efficiency of promoting the language of instruction in mathematics (earlier), especially for children who do not have a good command of this language**. During test taking it might also help to develop mathematical proficiency tests without verbal instructions and/or verbal task content to reduce language load, and to provide translations for children who do not have a good command of the language of instruction.

3.2.2.3 – Children's language background is affecting the identification of learning difficulties in mathematics

Finally Martini and colleagues (Martini et al., 2021) used ÉpStan data from children from cycle 3.1 to investigate how children's language background is affecting the identification of learning difficulties in mathematics. They divided the sample into different groups based on the languages spoken at home and examined whether and how using different reference groups impacted the number of children identified with an increased risk of learning difficulties (cut-off at the 25th percentile) or even a learning disorder (cut-off at the 10th percentile). When considering the entire sample as a reference, children from the Luxembourgish-German language group were under identified (7 and 19%) and children from other language groups were overidentified (e.g. 13 and 34% in the Portuguese language group) (Fig. 7). When separate cut-off values were applied for the individual language groups, differences emerged, with considerably higher values for the Luxembourgish-German group reducing under-identification and lower values for the other groups reducing over-identification (Martini et al., 2021). Therefore, it is crucial to take the students' language profile into account when diagnosing math learning impairments.

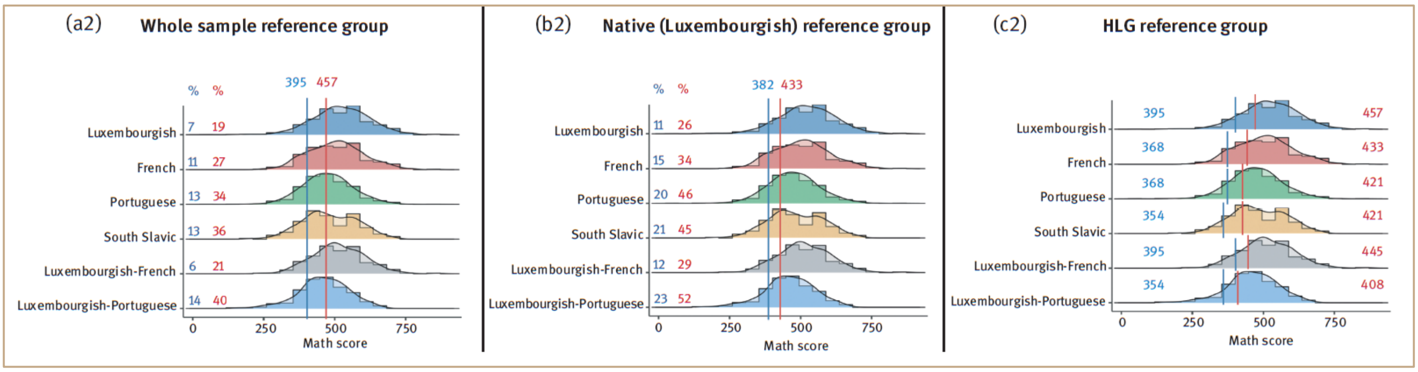

Figure 7. Cut-off scores for math scores (a2, b2, c2) for the whole sample (a1, a2), native (Luxembourgish) (b1, b2), and HLG reference groups (c1, c2). Per reference group, the cut-off score at the 10th percentile is shown in blue and the cut-off score at the 25th percentile in red. For the whole and native language reference groups, percentages of students below the 10th and the 25th percentiles are indicated in blue and red. (Figure 1, p.212 from (Martini et al., 2021))

3.2.3 – Arithmetic problem solving in LM1 (Ge) vs. LM2 (Fr) - Insights from experimental studies

Solving arithmetic problems relies on language, whether it involves retrieving arithmetic facts learned by heart or tackling more complex calculations (Dehaene, 1992). Only the approximation of arithmetic results is independent of language (Spelke & Tsivkin, 2001).

We evaluated how adolescents in various grades of secondary education in Luxembourg (7th, 8th, 10th, 11th year of formal education) and young adults within the same school system solve addition problems (Van Rinsveld et al., 2015). Relatively homogeneous groups of participants speaking Luxembourgish or German as home language and attending ESC after schooling in the Luxembourg school system since grade 1 were examined. As is common in scientific research, we separately analysed performance on very simple addition (operands <10) and more complex addition (operands >10). **The findings revealed that solving simple calculations was slightly faster in German (the first language of math learning – LM1) than in French (the second language of math learning – LM2) across all ages**. **However, the accuracy rate was similar for both languages**. Only in 7th grade did young adolescents make more errors in French than in German for this type of calculation.

For complex calculations (with solutions never exceeding 100), the advantage of German was even more pronounced. Across all age groups, these calculations were consistently completed more quickly and with fewer errors in German than in French. An analysis of the errors revealed that mistakes were more frequently made in the tens place in German and in the units place in French. For the addition 34 + 52 errors in German would thus be the answer 76 instead of the correct 86, while in French a typical error would be 87.

This data supports the notion that a person's linguistic background influences their approach to solving arithmetic problems. Students in Luxembourg's multilingual education system progressively improve their calculation skills in both German and French, while maintaining a certain advantage in German, the language in which they first learned mathematics.

This raises the question of whether computational performance in French can be improved. We explored this question and hypothesized that performance could be enhanced by allowing participants to process the language of the calculation before solving an arithmetic problem. In this 'language context' condition, participants first judged whether an auditorily presented sentence made sense before solving a visually presented calculation. This scenario was compared to simply solving arithmetic problems without prior language context activation. **The results clearly showed that presenting a language context had a beneficial effect on calculations in French (LM2), while performance in German (LM1) remained unchanged.** This finding aligns with Grosjean's proposal that the activation level of each of a bilingual's languages might depend on a context-dependent "language mode" (Grosjean, 2001).

Based on these results, one hypothesis is that **incorporating an adapted language context could enhance mathematical learning in the second language of instruction** (Van Rinsveld et al., 2016). However, it is also known that overly complex mathematical instructions can negatively impact performance. Therefore, when creating a language context, **it should be carefully tailored to the students' maturation levels.** Additionally, further studies in school settings are necessary before these findings can be applied to teaching practices.

To gain a better understanding of the cognitive mechanisms underlying calculation in multilinguals, we took advantage of the possibilities offered by functional magnetic resonance imaging. This technique makes it possible to determine which areas of the brain are activated by a given task. It is currently one of the leading techniques in cognitive neuroscience. In our case, we used it to highlight the brain regions activated in multilinguals when they solve addition tasks in the different languages they speak.

For this study, we recruited participants whose mother tongue is Luxembourgish, who completed their schooling in Luxembourg, and then attended French-speaking universities in Belgium. These participants were fluent in both German and French, having studied mathematics in German during primary school and in French during secondary school. They were asked to solve very simple sums (operands <10) and somewhat more complex ones (operands >10) in two separate test conditions, one in German and one in French. The tests revealed that participants could solve simple additions equally well in both languages. However, for complex additions in French, they required more time than for the same problems in German and made more errors. These behavioural results, obtained during functional magnetic resonance imaging, confirm the findings from our previous tests with young adults in a more conventional setting (Van Rinsveld et al., 2015).

During the test, the subjects' brain activity was measured using functional magnetic resonance imaging. The data revealed that different brain regions were activated depending on the language used. For simple additions in German, a small region in the left temporal lobe, associated with language and memory, was activated (Fig. 8). When solving more complex arithmetic problems in French, other brain regions responsible for processing visual information were also involved, indicating that the subjects relied on visual imagery (Fig. 9). The results do not support the hypothesis that the subjects translated the exercises from French to German to find the solution. While the subjects could solve problems in German by relying on brain regions typically activated by numbers, this system was insufficient for solving problems in French, the second language of instruction. In short, to solve arithmetic problems in French, the subjects had to systematically use other visual non-verbal thought processes, which are typically not observed in monolinguals.

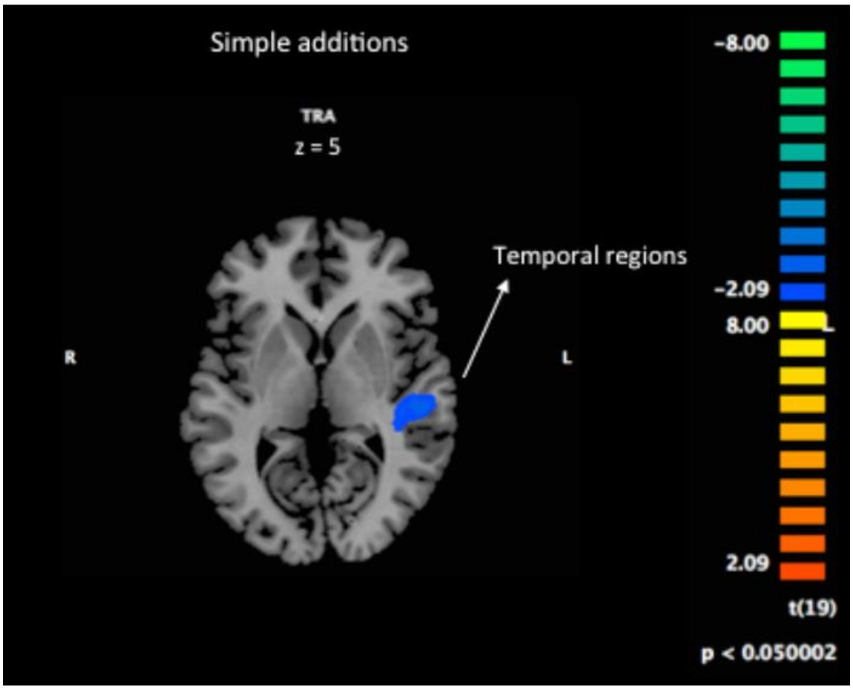

Figure 8. Activation maps for the contrast (French > German) or the simple addition task. Group analysis (random effect) revealed significant brain activity at p<.05 (Figure from in Neuropsychologia. 2017 Jul 1;101:17-29. doi: 10.1016/j.neuropsychologia.2017.05.009. Epub 2017 May 8

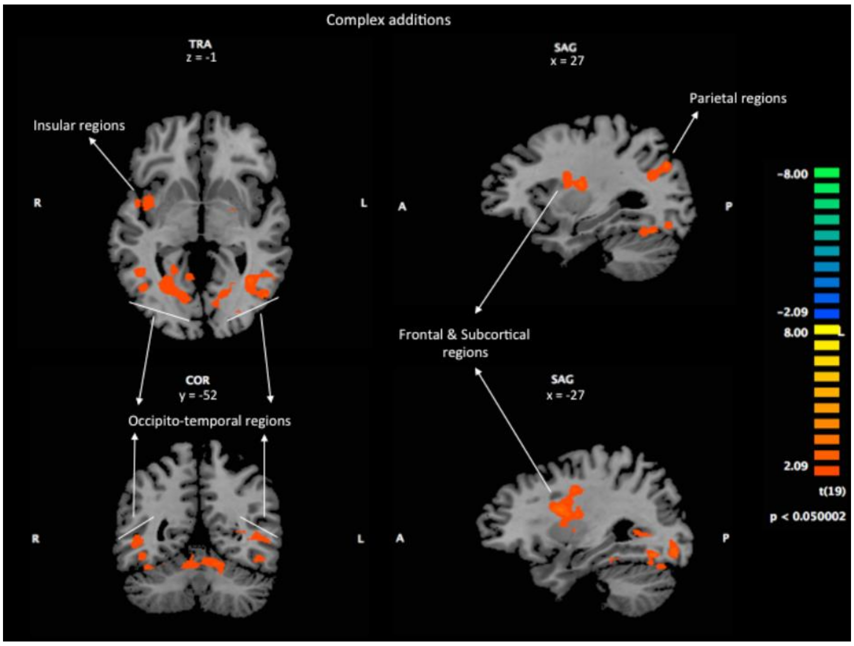

Figure 9. Activation maps for the contrast (French>German) for the complex addition task. Group analysis (random effect) revealed significant brain activity at p < .05. (Figure from Neuropsychologia. 2017 Jul 1;101:17-29. doi: 10.1016/j.neuropsychologia.2017.05.009. Epub 2017 May 8)

Using neuro-imaging techniques, the study pointed to the 'extra cognitive effort' required when solving mathematical problems in a second language of math learning (LM2). Additionally, the results clearly demonstrate that mathematical processes are directly influenced by language.

These findings are highly informative for the Luxembourg school system. While the use of two different languages in mathematics instruction allows pupils in Luxembourg's multilingual education system to perform mathematics in both languages, our behavioural and neurophysiological data indicate that this approach significantly impacts the cognitive processes underlying mathematics, which are sensitive to the language context of learning.

In the brain, the slower resolution of arithmetic problems in bilinguals' second language of math learning (LM2) is associated with more extensive neural recruitment, indicating less efficient cognitive processing in this language. This has been observed in German (LM1)-French (LM2) bilinguals in Luxembourg (Van Rinsveld et al., 2017) and Chinese (L1)-English (L2) bilinguals in the US (Wang et al., 2007).

In summary, bilinguals solve exact arithmetic problems more quickly and with fewer neural resources in the language in which they first learned them (L(M)1).

3.2.4 – Proficiency in LM1 (Ge) vs LM2 (Fr) number transcoding - Insights from experimental studies

Transcoding refers to the process of converting a numerical code into another form. For instance, naming 5 to /five/ is the transition from a visual code to a verbal code. During transcoding, the verbal codes of a bilingual's different languages may vary in their associations with the written code (i.e., Arabic numbers) based on linguistic status, similar to lexical-semantic associations described below in the section II.5.

When we examined how children, adolescents and adults attending the Luxembourg school system (10.7, 13.5, 16.5 and 23.6 years-old) are reading two-digit numbers, we found an advantage for German (i.e. LM1) compared to French (i.e., LM2). Please note that participants speaking French at home were excluded, as they might have acquired French number words outside the context of formal schooling. In addition, 10-year-olds attending cycle 4.1 were not only slower in French (i.e., LM2), but they also made significantly more errors (Lachelin et al., 2022).

In other words, the language of math learning plays an important role when a person is converting one numerical code into another. The fact that Luxembourgish sequential bilinguals (i.e., persons who attended the Luxembourg school system and learned math first in German (LM1) and then in French (LM2)) are slower at naming numbers in LM2 than in LM1 (Lachelin et al., 2022; Lachelin et al., 2023), probably reflects language switching costs, which are observed more generally in bilinguals (Saalbach et al., 2013). The slowdown is also in line with the meta-analytic finding that bilinguals typically perform more poorly in L2 than in L1 (Garcia et al., 2021).

The language of math learning even continues to impact number transcoding in multilingual young adults from Luxembourg. This simple numerical task is performed significantly faster in German (i.e., LM1) than in French (i.e., LM2). Nevertheless, and quite remarkably, for such a simple task, multilingual young adults from Luxembourg are slower in each of these two languages, compared to their German or French monolingual peers (Poncin, 2019; Lachelin, 2024).

Our results in Luxembourgish sequential bilinguals indicate that the first language of instruction in mathematics plays a significant role in learning.

They are especially relevant when aiming to design ideal learning conditions for 12-year-olds moving from primary to secondary education in the Luxembourg education system. Changing the language of instruction in mathematics from German to French appears to cause a slowdown, as well as a certain number of errors in mathematical productions. It might thus be advisable to adapt instruction such that this difficulty is recognised and addressed in the teaching methods and content. This assumption will need to be verified by future intervention studies.

3.2.5 – Access to one-digit magnitude in LM1 (Ge) vs. LM2 (Fr) - Insights from an experimental priming study

Bilinguals have access to (at least) two number word formats (in L1 and L2). Therefore, they must deal with more numerical representations than monolinguals. As a result, it is possible that for bilinguals, number representations in one language are not automatically available in another.

Our studies with adult bilinguals fluent in German and French who attended the public Luxembourgish school system confirm the independence of the lexical-semantic associations of each of a bilingual's languages. Number words in German or French were briefly presented as a prime and followed by Arabic numerals that had to be named in both languages. Priming produced a distance effect with number words in LM1, but not in LM2 (Lachelin et al., 2023), thus demonstrating stronger number magnitude representations in LM1 than LM2.

3.2.6 – Measuring Short-Term Memory Span using numbers - Insights from a large-scale experiment

The quality of number word representation and their lexical access even influences the assessment of cognitive capacities, which often uses number words as test stimuli. In two cohorts of Luxembourgish sixth graders (2021 and 2022) Kijamet and colleagues (2024) thus demonstrated that L2 pupils had a smaller memory span than L1 pupils in a digit-span task using Luxembourgish numbers, but no significant differences between L1 and L2 groups were found in a non-word-span task using word-like stimuli that do not exist in any language and are thus language-neutral (Kijamet, 2024). Using number words in a language differing from children's home-language to assess their memory capacity would thus lead to an underestimation of their short-term memory and their cognitive potential more generally. The cognitive potential battery deployed for 6th graders in Luxembourg therefore now uses language-neutral non-word rather than the classically used digit to evaluate short-term memory.

3.3 – What can be done to enhance math learning in a multilingual context

Language plays a fundamental role in the acquisition of basic and advanced mathematical concepts. Moreover, language skills of increasing complexity are required to manage mathematical tasks that become increasingly complex in higher grades (Kleemans & Segers, 2020; Vukovic & Lesaux, 2013).

> In this context, acquiring mathematical skills can be particularly difficult for children whose home language does not correspond to the language of school learning (L2). Indeed, lack of proficiency in the language of mathematics instruction is an important reason why L2 children are generally at a disadvantage in large-scale standardised tests (e.g., Greisen et al., 2021; Ugen et al., 2013).

This disadvantage adds to the effects of socio-economic status and migration background and it contrasts sharply with the fact that teachers tend to believe that mathematics contains a minimum of language and therefore fewer linguistic challenges than other subjects (Fernandes, 2023).

3.3.1 – Recognize and address the influence of language on math learning

> Based on their data obtained with cycle 1 pupils, Hornung and colleagues (2023) are suggesting **to promote a continuity of languages between early childhood education and subsequent schooling** to prevent performance gaps in German listening comprehension with L1 outperforming L2 pupils as currently observed from cycle 2.1 (Hornung et al., 2023).

They are suggesting to foster plurilingual education via projects such as the "ALPHA - Zesumme wuessen" which is offering the choice between alphabetisation in French or German (https://www.script.lu/fr/activites/innovation/alpha-zesumme-wuessen) and European and international schools. **They are also proposing to explicitly promote the language of alphabetisation in early childhood education to foster the basis of alphabetisation.**

Given the demonstrated associations between skills in German (reading) comprehension and math performance (Greisen et al., 2021) such actions also appear as highly pertinent for math education, as they would very likely promote L2 children's math skills as well.

These data also **argue in favour of a continuity between languages of instruction for literacy and numeracy acquisition,** such that children undergoing alphabetisation in French should also acquire math in French. Finally, language interventions could also consider the difficulties associated with the specific lexical structures of number words, such as the inversion of tens and units in German or the vigesimal structure for certain French numbers.

3.3.2 – Recognize and address the additional effort required when switching the language of math instruction

Our experimental results clearly demonstrate the existence of a cost for numerical and mathematical thinking in a second compared to the first language of math learning (LM2 vs. LM1)(e.g., Lachelin et al., 2022; Lachelin et al., 2023; Van Rinsveld et al., 2015; Van Rinsveld et al., 2017). It appears that activating the French (LM2) language context before calculations in French might be helpful and could be explored with future intervention studies (Van Rinsveld et al., 2016).

To address these costs more generally, one might consider adjusting the math curriculum during the first years of secondary school, and possibly also already in C4 of fundamental, by including explicit learning and instruction of math vocabulary in French.

In addition, **offering curricula which allow maintaining the language of math learning throughout education (e.g. EU-PS) will provide another highly valuable option** (Luxembourg Centre for Educational Testing (LUCET) & Service de Coordination de la Recherche et de l'Innovation pédagogiques et technologiques (SCRIPT), 2023); see also part 1, *supra*). This option might be especially beneficial for children who want to limit the language load due to their highly multilingual profile or due to special education needs in the field of mathematics or reading and writing (McClung & Arya, 2018). These actions should ideally be empirically evaluated and validated before implementation (as already partially done for the EU-PS approach).

3.3.3 – Develop language-neutral interventions to foster (early) math

The above-mentioned approaches, address the language-related challenges for math learning by targeting the language of instruction via offering additional support in language learning or alternative language of instructions. As a complement, one can also capitalize on the specific nature of mathematics and its tight relations with visuo-spatial abilities (Hawes & Ansari, 2020) to design interventions which foster math abilities in a language-neutral manner. A team around Pazouki and Cornu used this approach to design the tablet-based training "MaGrid" for early math in cycle 1 children (Pazouki et al., 2018).

“MaGrid” is a tablet-based app offering a variety of training tasks focused on fundamental mathematical concepts for preschoolers. It is characterized by language-neutral design, such that all task instructions are conveyed by short videos. “MaGrid” supports interactive, individual learning with real-time feedback and records students' activities, helping teachers and parents monitor progress and observe improvements over time. While it can support all learners, it is especially pertinent to help reducing language barriers for L2 learners in multilingual settings. After being developed by the University of Luxembourg, it was distributed to all C1 classes in Luxembourg and is now being further developed and internationally promoted in the context of the LetzMath start-up (https://magrid.education/, fig. 10).

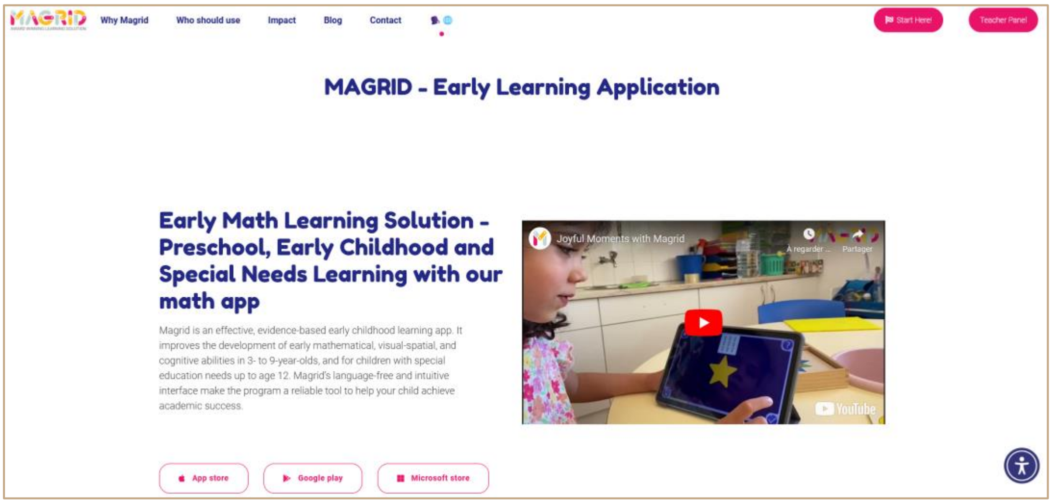

Figure 10. Screenshot of the MaGrid application website https://magrid.education/.

3.3.4 – Design tailor-made diagnostic tools to identify special education needs pupils

An important diagnostic criterion for dyscalculia, or specific mathematics learning impairment, is that difficulties cannot be explained by a lack of understanding of the language of mathematics instruction (*ICD-11 International Classification of Diseases 11th Revision The Global Standard for Diagnostic Health Information*, 2019). Since psychometric tests assessing mathematical ability for diagnostic purposes are typically based on language instructions, performance may be influenced by language skills, increasing the risk of misdiagnosis (Ugen et al., 2021).

Consequently, when diagnosing dyscalculia children who are less proficient or who do not speak the main language of math instruction at home need to be considered with particular attention.

The study of Martini and colleagues (2021) impressively confirmed this with EpStan data from C3.1 and suggested that diagnostic tests should include separate reference standards according to the children's language of origin and competence to avoid over- and under-diagnosis (Ugen et al., 2021) in multilingual environments such as Luxembourg.

Consequently, researchers from the LUCET are currently developing the “Luxemburger Testbatterie für Mathematik im Zyklus 3.1” (LuxMatheTest), which is tailor-made for math education in the multilingual school system of Luxembourg. It will include reference standards and descriptive values per subtest and separately for the four language background groups: Luxembourgish/German, French, Portuguese and other languages. This should help avoid yielding too high or too low identification rates of learning difficulties and learning disorders for L2 and L1 children respectively (Hilger et al., 2024).

3.4 – Conclusion – Numbers and mathematics bear the fingerprint of language(s)

In summary, the language profile and context influence numerical and mathematical thinking. Using different methodological approaches from cognitive neuroscience, we have been able to show that simple numerical tasks such as reading numbers and more complex tasks such as solving arithmetic problems are marked by language. These language imprints are not confined to the learning process but persist to the stage of mastery and automaticity (e.g. retrieval of arithmetic facts from memory) achieved in adulthood.

Recent studies also show that bilingualism may in some specific cases improve executive functions but often leads to academic difficulties when the language of instruction differs from the home language. In Luxembourg PISA and "Épreuves Standardisées" thus consistently reveal that L2 students score lower than L1 students in math, with significant differences increasing from grade 1 to grade 9. Since two-thirds of the pupils do not speak German or Luxembourgish at home (L2) and given that math abilities relate to full-time employment and socio-economic status this calls for tailored educational measures.

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