School mixing: more equity through intelligent school zoning

Optimized school catchment areas for Swiss cities

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Summary

Objective, data and methods

International studies point to increasing social and ethnic segregation among urban schools. This is problematic because social and ethnic composition of schools has a demonstrable effect on student achievement, regardless of individual background. In no OECD country are these so-called composition effects as pronounced as in Switzerland. While elsewhere a newly introduced free choice of schools and the influx of private schools are blamed for unequal school conditions, the different composition of schools in Switzerland is mainly due to the segregation between residential quarters and corresponding school catchment areas. This ZDA study examines this relationship using the example of elementary school in Switzerland's six largest cities (Module 1). At the same time, it examines for these cities the possibilities for greater mixing through small-scale adjustments of the catchment area boundaries (Module 2). For optimization purposes, a novel, detailed algorithm was developed, which in the future could be transferred into an auxiliary tool that supports school assignment and school space planning. The focus is not on the assignment of individual pupils, but on the development of proposals for the adjustment of catchment areas at their boundaries. The catchment areas remain contiguous and short and safe walking distances to school are provided (principle of "neighborhood school", no school transportation). In a qualitative part of the study, the current practice of school assignment and school space planning is examined, based on expert interviews with representatives of school authorities (Module 3). In addition to the practice, we identify the challenges in mixing as well as the requirements for a possible optimization tool.

For the quantitative analyses, we use geocoded data on lower school pupils (by cut-off date) from the 2000 census, as well as supplementary samples of the resident population from the 2010 to 2018 structural surveys, furthermore data from cantonal education statistics, and unpublished data from individual school authorities on school catchment areas for the 2019/20 school year. For the preparation, recoding, analysis, and presentation of the data we use the geographic information systems QGIS and ArcGIS, as well as the statistical software R. The Java-based optimization algorithm (local search algorithm - 'Hillclimbing') accesses these data and consults further geo-coded data for the simulation of individual school routes (OpenStreetMap, forest areas according to swisstopo, MATSim traffic model of the national passenger transport model "NPVM", safe school route crossings according to school instruction). As output, the algorithm provides tabular and spatial data for configurable conditions (maximum school route length, school capacities) for the individual optimization steps.

Main results of the study

The extent to which the social and cultural composition of schools affects school performance in Switzerland is shown not only by previous international and national research, but also by the analyses conducted specifically on the reading performance of secondary school students (PISA 2000) and on the German language performance of 3rd primary school pupils in the canton of Zurich (Zürcher Lernstandserhebung 2006). Earlier findings can be confirmed, according to which:

- a low to middle social mix in schools is not associated with a significant drop in performance, but this only sets in at a proportion of around 30 to 40 percent of pupils from socially disadvantaged and foreign-language families (tipping effect).

This finding is of high political relevance. It means that mixing schools creates more equal opportunities for children and young people from particularly disadvantaged neighborhoods without compromising the performance of other children and young people.
Analogous to school performance, typical educational paths also differ according to the composition of schools, which can be impressively demonstrated by evaluating the transfer rates in the school districts of the cities studied. Here, these spatial divergences initially reflect the different individual backgrounds of the children (parents' educational level, linguistic-cultural barriers), but are amplified by compositional effects at the school level. A child in a school with a high concentration of children from educationally disadvantaged and poorly integrated families has been shown to have more difficult access to more demanding schools at secondary level than if the same child attended a school with a more favorable composition in a different neighborhood. Despite processes of upgrading and a "new" immigration of educationally advantaged population strata, the differences between school districts have remained large over the past two decades, both in the city of Zurich and in the other cities studied.

Regarding the relationship between segregated neighborhoods and the composition of schools (Module 1), the analysis of data on primary school pupils (2000 census) shows that:

- in the cities studied, the composition of schools by linguistic and socioeconomic origin largely reflects the composition of the schools' immediate neighborhoods or residential segregation is even exacerbated in certain school districts. The effect of segregation, especially in disadvantaged neighborhoods, is generally not reinforced by the specific layout of the catchment areas, but neither is it mitigated.
- there are considerable differences in the composition of schools by language and socioeconomic background.

Regarding room for maneuver for greater mixing (Module 2), the optimization algorithm based on data on primary school pupils (2000 census) shows that:

- small-scale adjustments to the catchment area boundaries can create a considerable balance between the schools, whereby a mixing of the most burdened schools can succeed even if the existing school capacities and maximum school route lengths are adhered to.
- an extended leeway regarding school capacities and maximum school route lengths, if necessary combined with more permeable catchment areas, can further increase the mix depending on the city studied.
- the equalization through small-scale adjustments is significantly greater within school districts than across the city.
- the location of existing schools, as well as their accessibility, strongly influence local optimization possibilities.
- disproportionate concentrations in individual schools (in relation to the surrounding ‘neighborhood’) can, with a few exceptions, be explained by their isolated location (highways, railroad tracks).
- a stronger leveling between the school districts requires a detachment of school space planning from the school district boundaries as well as a selective flexibilization of the maximum school route length.

Supplemental analyses of 2019/20 school neighborhoods based largely on residential population samples (2010 to 2018 pooled structural surveys) indicate that:

- upgrading processes have resulted in several schools with previously highest concentrations now ranking in the middle. This shifts the focus to the neighborhoods that continue to be burdened complemented with individual neighborhoods of rising concern.
- the segregation patterns around these neighborhoods today still indicate considerable potential for mixing among the schools in question.
- catchment areas in force today are most likely to reproduce social and ethnic residential segregation one-to-one even today.
• new school locations have contributed little to mixing, depending on the location chosen.

School board representatives interviewed in Module 3 from the cities of Zurich, Bern and Winterthur reveal the current practice of school assignment and school space planning. These interviews also provide insights into the challenges of mixing and the requirements for a possible optimization tool.

**Recommendations**

Schools with high concentrations of children from educationally disadvantaged families or families with little familiarity with the school system face significant challenges in teaching basic skills and providing fair access to more demanding types of schools at secondary level. At the same time, schools with predominantly children from educationally advantaged and well-integrated families would also benefit from greater mixing. Learning to deal with diversity at an early age strengthens social skills and is also in demand in the internationally highly networked labor market and strengthens social cohesion across neighborhoods and social and cultural boundaries.

The results of the study suggest that the social integration potential attributed to the early stages of public schooling is still little exploited in the cities studied. Segregation by place of residence is reproduced almost one-to-one with the catchment areas in effect today, while the data-based analysis for the 2000/01 school year reveals room for maneuver to achieve greater mixing.

Specifically, this study formulates the following recommendations:

• The aspect of mixing by social and linguistic background or by performance should not only be considered when assigning pupils to classes within schools, but already when determining the catchment areas, so that the greatest possible mixing between schools is made possible.

• Social and ethnic mixing between schools should also be an important goal of school space planning. Opportunities for greater mixing should be considered in expansions as well as in the designation of new school locations. To achieve greater mixing of schools in isolated locations, capacity shifts should be examined, as should structural and traffic planning measures to improve accessibility from other neighborhoods.

• Urban development policy and private and non-profit housing have a central role to play in achieving mixed neighborhoods and thus mixed schools. Even if upgraded neighborhoods go hand in hand with more mixed schools, at least initially, it should be ensured that, during renewal and densification, socially vulnerable families are not simply pushed into the remaining socially burdened neighborhoods or out of the city altogether.

• Targeted mixing in school assignment, as well as considerations of capacity shifts and new school locations, should be facilitated by a data-driven analysis tool. The algorithm developed here could easily be integrated into existing assignment procedures without significantly changing the work of school allocators. For the social acceptance of adapted catchment areas, it is important to disclose how the algorithm works and to transparently communicate the politically determined target values together with the indicators that are being used.
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Introduction

The idea for this study arose in the context of the international research project "The Democratic Foundations of the Just City", funded by the Swiss National Science Foundation and conducted in collaboration between the Centre for Democracy Aarau (University of Zurich) and the University of Birmingham (UK) (2017-2020). That project focused on urban renewal and housing policies for a "just city," drawing on the political theorist and urban researcher Susan Fainstein (2010) as well as to the concept of "spatial justice" according to geographer Edward Soja (2010). If Fainstein is concerned with the social impact of urban development projects and the free development of individual capabilities (vgl. Nussbaum 2000), Soja emphasizes the spatial character of permanent disadvantages of certain population groups and the underlying political, economic, and social processes. In particular, he criticizes unequal access to life chances, refers to segregation processes in U.S. schools, to the problem of the banlieues in France, and to displacement processes in the core cities of globally networked metropolises. Accordingly, the international research project examined urban renewal and housing policies against the background of socially and ethnically segregated residential neighborhoods and gentrification processes in selected cities (Zurich, Lyon, Birmingham).

In addition to the international research project, we first conducted a pilot study on the city of Zurich and now, in the extended study on the five next-largest Swiss cities, we focused specifically on school policy and its possible role in working toward socially mixed schools in the context of existing residential segregation - i.e., socially and ethnically segregated neighborhoods. The significant influence of the composition of schools on the performance of individual students is well known and has been amply demonstrated throughout PISA studies for the broad circle of OECD countries. The composition of schools according to socioeconomic characteristics and, depending on the country, also according to migration status has an influence on school performance, regardless of the individual background of each student. The most recent publication shows the strongest so-called "composition effects" for Switzerland: student performance is significantly lower in schools with above-average proportions of migrants, and this is true even when the socioeconomic status of individual students and the socioeconomic composition of the school are taken into account (cp. Figure 86 in the appendix; OECD 2016). Since in Switzerland the same child has different chances of success at school and in further personal and professional development depending on the composition of the school attended, the mixing of schools is a central prerequisite for institutionally ensuring equal opportunities.

While elsewhere a newly introduced free choice of schools and the influx of private schools are blamed for unequal school conditions, the different composition of schools in Switzerland is mainly due to segregation between residential quarters (residential segregation). The central mechanism for the relationship between residential segregation and segregation between schools in Switzerland, as elsewhere, is school catchment areas. These are usually based on existing neighborhoods, with school routes kept as short and safe as possible, especially at the lower and middle (primary) school levels. The school catchment areas are determined by the municipal or cantonal school authorities and assign each school-age child to the school to be attended, depending on the residential address. This study is therefore primarily concerned with the role of school catchment areas in the (possible) mixing between schools. Since the locations and capacities of the schools also play an important role in the (possible) mixing of schools, the study also considers the planning of school space.

This report is organized as follows. Since the present study on school mixing is essentially based on the finding of unequal learning conditions depending on the composition of schools, we first present the previous findings as well as our own evaluations on the effects of school composition ('composition effects') in Switzerland, including the question of so-called 'tipping effects'. As an introduction to the following analyses, the initial situation regarding unequal access to educational opportunities is briefly outlined for all the cities studied, depending on the neighborhood in which they live. This is followed by a summary of international research on school segregation, the effects of school catchment areas, and existing approaches to optimizing these catchment areas. Following this, the data and methods used for the study are presented. The empirical findings are then presented.
separately by project module for all the cities studied. Module 1 will first examine the relationship between residential and school segregation. The focus is on the question whether the existing catchment areas of the lower primary schools in the cities studied strengthen or weaken the effect of residential segregation. In Module 2, we ask about the room for maneuver of school authorities: can a stronger mix be achieved with small-scale adjustments of catchment area boundaries? To simulate alternative catchment areas, a novel, detailed algorithm was developed in the pilot study, which could in the future be transferred into an auxiliary tool supporting school assignment and school space planning. The goal is not to allocate individual pupils, but to develop proposals for adjusting catchment areas at their boundaries. The catchment areas remain contiguous and short and safe walking distances to school are provided (principle of “neighborhood school”, no school transportation). In a qualitative part of the study, the current practice of school assignment and school space planning is briefly described, for which, in the case of the cities of Zurich, Bern and Winterthur, we conducted expert interviews with representatives of the school authorities (Module 3). In these interviews, we identify challenges in mixing as well as requirements for a possible optimization tool. The report concludes with a summary of the findings and the recommendations derived from them, followed by an epilogue on how the study findings fit into the current debate on educational equity in Switzerland.
Unequal access to education in Switzerland

In the following, we will first outline the existing and our own evaluations of the effect of the social and cultural composition of schools on school performance (composition effects) in Switzerland. These effects form a central motivation for the present study. As an introduction to the analyses that follow, we also briefly outline the initial situation for all cities with respect to unequal access to educational opportunities in dependency to residential neighborhood.

Composition effects in Switzerland

With respect to Switzerland, PISA studies regularly show that individual educational success is disproportionately shaped by social and ethnic origin. In addition to this individual effect, however, the social and ethnic composition of schools in no other OECD country has such a pronounced effect on individual student achievement as in Switzerland (cp. Figure 86 in the appendix; OECD 2016; cp. Erzinger, Jäger-Biela, and Hauser 2019). The share of private schools in Switzerland remains comparatively low (4%) - despite various political initiatives to subsidize private schools and introduce free school choice - and assignment to public schools continues to be made by local (partly cantonal) school authorities (Diem and Wolter 2011; Oelkers 2008). Instead, it is the residential segregation that can be observed in Switzerland (cp. Heye and Leuthold 2004; Ibraimovic 2011; Craviolini 2019; Zufferey 2019) which can lead to class compositions that have a negative impact on individual school performance. This is the case even if accounting for compensatory measures such as the "Quality in Multicultural Schools" (QUIMS) program in the canton of Zurich (Moser et al. 2011; Maag Merki et al. 2012). Thereby, the first years of schooling and pre-school support have a key role, since the achievement gap of disadvantaged children increases continuously over the school years (Grossenbacher 2012; Moser 2012).

Maja Coradi Vellacott (2007) uses PISA data to estimate the threshold for a negative composition effect at a proportion of 40 percent of foreign-language students and explicitly examines the role of socio-spatial segregation between Swiss communities, assuming similar correlations between urban neighborhoods as well. In doing so, Coradi Vellacott argues that status-high individuals, when choosing where to live, also immediately ensure that their children go to school with peers from "good homes". Foreign and socioeconomically disadvantaged individuals, in contrast, rely on affordable housing and financially feasible commutes to work. Indeed, high status individuals are overrepresented in low-tax communities with high proportions of single-family homes, while foreigners are underrepresented in such communities. At the same time, using PISA data, she shows that schools in low-tax communities and in communities with a high proportion of single-family homes have better physical facilities. Thus, segregated foreign-language and socioeconomically disadvantaged students would be at a triple disadvantage (Coradi Vellacott 2007, 190). First, by a less supportive family and social environment; second, by an unfavorable school composition; and third, by poorer material resources at school, the combination of which can have an unfavorable effect on the motivation of teachers as well as on the school climate. Already before Coradi Vellacott, Moser and Rhyn (2000) had estimated composition effects, at that time at the class level and based on an evaluation of school success in the 6th grades of elementary school in the canton of Zurich. Due to the difficulty of disentangling composition effects by social background and by proportion of foreign speakers, they focused on the proportion of foreign speakers and found a similar tipping effect, according to which performance in German and mathematics deteriorates significantly only above a proportion of 30 percent of foreign speakers (first language/colloquial language at home), with the achievement gap estimated at around 5 percent. In a more recent study based on the Zurich Learning Survey, Moser et al. (2011) find class effects, according to which a 50 percentage point increase in the proportion of learners with German as a second language at the end of elementary school leads to a learning gap in German of half a year, while a very high proportion of socially privileged pupils leads to a learning advantage of one year. It would have been interesting to examine class effects for a high proportion of socially disadvantaged pupils. Current evaluations of composition effects in
Switzerland (Erzinger, Jäger-Biela, and Hauser 2019) again refer to the PISA survey of 15-year-old secondary school students, where a 50 percentage point increase in the proportion of students with a low socioeconomic status (lowest decile according to the ESCS index) at a school leads to a drop in performance in German and mathematics of 43 points each. This drop applies to a scale in which around two thirds of the students tested across the OECD lie in a value range between 400 and 600 points. At the same time, a 50-percentage-point increase in the proportion of foreign-language students is accompanied by a drop of 49 points in German and 34 points in science. It should be noted that the authors have only estimated linear correlations between the respective proportions of students and school performance in their models, without checking whether the underlying data rather point to tipping effects as revealed by Moser and Rhyn (2000). Erzinger et al. explicitly leave the question of possible tipping effects open with reference to Moser and Rhyn (2000).

There is widespread agreement in the research community that both the social status aspect and the foreign language aspect play a central role in explaining school performance, and this applies both to the effect of individual background and to the effect of the composition of schools and classes. In order to reflect both aspects with regard to the degree of mixing and the mixing potential of the schools in the following analyses, we will use a combined ‘concentration index’ in the present study, which is calculated\(^1\) from the mean of two proportion values:

The proportion of foreign language pupils on the one hand and the proportion of pupils whose parents have a low formal educational background on the other (see chapter Data and Methods).

To complement the reported findings, the compositional and tipping effects will now be examined using such a concentration index. Since the PISA survey refers to students at the end of compulsory schooling, it is crucial for corresponding regressions to control not only for the different cantonal and linguistic-regional school systems, but also for the already occurred selection of students to school types of different proficiency levels. Since the national data sets with the required information for the more recent PISA surveys in 2015 and 2018 were not available at the time of writing, we have chosen to evaluate the first PISA survey from the year 2000, which also allows us to comply with the timing of the optimizations performed in the present study. This choice also has the advantage that a larger number of students and schools were tested for the earlier PISA surveys thanks to additional national samples.

To identify tipping effects in the relationship between school performance and school composition specific to the more heterogeneous urban areas, only schools in municipalities with more than 15,000 inhabitants were considered for the analyses reported here.\(^2\) The schools sorted by concentration index were divided into four equally sized groups (quartiles), and the effect of school group membership was estimated using multivariate multilevel regressions (see regression in the Appendix). Figure 1 illustrates on the one hand the average effect of individual background on reading achievement for a privileged and for a disadvantaged student (male)\(^3\) respectively (red and blue bars), but at the same time it shows the predicted values for the same students according to the composition of the school attended. Indeed, the regression analysis confirms a tipping effect for schools with concentration scores above 32 percent. Thus, if the same student was to attend a school with the highest concentration scores instead of a school with the lowest concentration scores, his predicted reading achievement drops by 49 points. Measured against the OECD-wide score scale with a mean of 500, where about two-thirds of the students score between 400 and 600, this is a substantial amount. With the chosen representation, this school effect can also be put in relation to the individual effect, which is somewhat higher at 80 points. However, the school effect found is in no way negligible. Even if the points achieved by the prototypically depicted students may in reality scatter

\(^1\) Compare ‘Mixed Index’ within the QUIMS program of the education department of the canton of Zurich: Mean proportion of foreign speakers + foreigners.

\(^2\) The data set contains a variable to identify municipalities with more than 15,000 or more than 100,000 inhabitants. However, selecting only schools in cities with more than 100,000 inhabitants would no longer have allowed a meaningful statistical analysis due to the small number of schools tested. If, on the other hand, all tested schools in Switzerland were taken into account, schools with concentration values from 15 percent already fell into the quartile with the highest concentration values. As expected, at this very low threshold, no statistically significant effects of group membership on reading achievement could be detected (results not reported).

\(^3\) Male students are generally predicted to have lower reading achievement than female students, other things being equal. For female students, all predicted values in Figure 1 would be 16 points higher (see regression in the appendix).
around the depicted predicted values to a considerable extent (i.e., also below and above the depicted range), the figure impressively shows the more difficult learning conditions in schools with particularly high concentrations. While the depicted effect for schools in the fourth quartile shows high statistical significance compared to schools in the first quartile, the predicted values in schools in the second and third quartiles fluctuate randomly around the values of schools in the first quartile. This result thus indicates a tipping effect, which sets in for schools with a share of around one-third or more individually disadvantaged children.

Figure 1: Predicted reading achievement of secondary school students in Swiss municipalities over 15,000 inhabitants, PISA 2000

Legend: On a standardized score scale with an OECD-wide mean of 500 and standard deviation of 100 (i.e., about two-thirds of the tested students across all OECD countries scored between 400 and 600 points), disadvantaged students score 80 points lower than privileged students (individual effect; difference between red and blue bars). If these students attend a school belonging to the quarter of surveyed schools with the highest concentration scores (effect of school composition) (Q4: fourth quartile), scores are expected to be 49 points lower than if the same students would attend a school belonging to the quarter with the lowest concentration scores (Q1: first quartile). In contrast, no systematic drop in performance can be observed for schools in the second and third quartiles Q2 and Q3. The tipping effect thus sets in for schools in the 4th quartile. The underlying multivariate multilevel regression is reported in the appendix.

Similar results are obtained from the analysis of the 2006 survey of learning levels in the large and strongly urbanized canton of Zurich. Figure 2 shows the results of the multivariate regression analysis (see appendix) using the example of proficiency of the school language (standard German) at the end of the 3rd primary grade. Again, no significant drop in performance can be found in the schools of the second and third quartile compared to schools of the first quartile. This means that the indicated fluctuations in the figure occur by other non-observed factors. Once more, a significant tipping effect can only be identified for schools in the 4th quartile, with this quarter of schools showing concentration scores of 40 percent or more. Again, the school effect of 35 points versus the individual effect of 78 points represents a non-negligible factor in school performance.
Predicted German proficiency at the end of the 3rd primary grade in the Canton of Zurich, Zurich Learning Survey 2006

- Pupil (male): high social status (SES=+1 SD), first language German
- Pupil (male): low social status (SES=-1 SD), foreign speaker

Figure 2: Predicted proficiency in school language (standard German) by individual background and by class composition.

Source: Own evaluation based on Zurich Learning Survey 2006, provided by the Department of Education of the Canton of Zurich.

Legend: On a standardized score scale with mean 500 and standard deviation 100 (i.e., about two-thirds of the tested pupils scored between 400 and 600 points), disadvantaged pupils score 78 points lower than privileged pupils (individual effect: difference between red and blue bars). If pupils attend a class belonging to the quarter of surveyed classes with the highest concentration scores (effect of school composition) (Q4: 4th quartile), scores are expected to be 35 points lower than if the same pupils would attend a class belonging to the quarter with the lowest concentration scores (Q1: 1st quartile). In contrast, no significant drop in performance can be observed for classes in the second and third quartiles Q2 and Q3. The tipping effect thus sets in for schools in the 4th quartile. The underlying multivariate multilevel regression is reported in the appendix.

Although the issue of residential segregation and the negative composition effect has been included in all national education reports (SKBF 2004; 2010; 2014; 2018), making reference to the work of Coradi Vellacott, among others, they initially referred only to the linking of staff resources to the social index in the canton of Zurich. More recent reports then added reference to the school programs for particularly stressed schools in the canton of Zurich (“Quality in Multicultural Schools” - QUIMS) and in the canton of Geneva (REP), further to the pedagogical benefits (peer effects) of day structures and finally to the specific development of teaching materials for multilingual schools. So far, nothing has been learned about the possibility of school authorities to influence the school composition themselves.

Initial situation in the cities studied

For Switzerland, there has also been qualitative research on selected cities which would treat the topic of residential segregation and targeted mixing in schools. For the schools in the Bern West district, different approaches practiced in dealing with social and cultural diversity have been highlighted (assimilation vs. integration, selection process), as well as the city’s efforts to promote the influx of high-achieving middle-class children through upgrading and image policies (Oester, Fiechter, and Kappus 2005). Another study takes up the obligation of the Bernese school authorities to strive for a social mix within the school districts (municipal school regulations) and to counteract a “ghettoization” of the school through increased mixing of foreign and native children (integration model of the city of Bern), whereby the responsible persons interviewed refer to the need for traffic planning measures, social housing construction and upgrading of public space, and the real possibilities for control are estimated as rather low (Zychlinski et al. 2015). Furthermore, a study on the social transformation processes in
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Zurich Schwamendingen documents the efforts of the authorities to counteract the increasing segregation within the framework of their neighborhood development policy since the end of the 1990s, including traffic calming measures, securing school routes and the renewal of public space (Eberle 2009). Finally, perceptions of ‘collective disadvantage’ by residents in ‘precarious neighborhoods’ are documented with reference to the schools in Zurich's Longstreet neighborhood, among others (Berger, Hildenbrand, and Somm 2013).

By way of introduction to the cities studied here, the following sections illustrate for each city how access to education varies by neighborhood against the backdrop of socially and culturally segregated residential neighborhoods. In the absence of (accessible) school performance data at the level of schools or neighborhoods, access to education, where made available, is based on transfer rates from elementary school to different types of secondary education at a spatially highly aggregated level. After all, the lower primary school performance in high-stress schools discussed above also affects students' subsequent school careers. The following illustrations of transfer rates are not intended to suggest that as many students as possible should attend a Gymnasium (highest requirements). Rather, the aim is to show how the composition of the neighborhoods - and thus also of the schools - also manifests itself in the frequency of transfers to the less demanding secondary school types.

Zurich (pilot study)

How school segregation and residential segregation are related and what role the real estate industry and urban housing subsidies play in this context was recently discussed in a thematic issue of the magazine Hochparterre. Using the city of Zurich as an example, we used the following and other cartographic analyses to show how strongly educational opportunities depend on the school district and the social and ethnic composition of the resident population. Figure 3 clearly shows the differences in typical educational paths depending on the school district. While more than half of all sixth-graders in the Limmattal school district switched to the secondary school B (lower requirements) in the 2000/01 school year (darker area in the northeast), only about ten percent of all sixth-graders in the Zurichberg school district (lightest area) did so, whereas almost forty percent of the latter managed to transfer directly to the Gymnasium (highest requirements). The disparities between the school districts have remained high over the past two decades. As a recent study on the differences in housing rents directly at the Zurich school district borders shows, better-off parents take these differences into account when choosing where to live (Bircher 2017).

In fact, the darkly marked school districts in Figure 3 also have the highest number of people with low formal educational attainment (Figure 4) and foreign nationality (Figure 5). In the past, an urban area with socioeconomically, linguistically and culturally aggravating conditions for education stretched from the main train station to the city limits in the west. Today, there are only isolated neighborhoods in Zurich with a high proportion of people with low social status: Hard, Grünau and Schwamendingen (Figure 4, right). The reasons for this are sociodemographic developments, highly qualified immigrating workers, and gentrification and displacement processes.

If data on transfer rates by school or by neighborhood were available, they would probably accurately reflect the social and ethnic composition of the resident population (or student body) in all the cities studied. In this context, these spatial divergences initially reflect the different individual backgrounds of the children (educational level of parents, linguistic-cultural barriers), but are exacerbated by the compositional effects at the school level mentioned at the outset. A child in a school with a high concentration of children from educationally disadvantaged and poorly integrated families has aggravated access to more demanding types of schools than if the same child attended a less stressed school in a different neighborhood.

* https://issuu.com/hochparterre/docs/hochparterre_quartierentwicklung_20 (accessed 10/17/19)
Figure 3: Transfers from public elementary school to secondary school types by school districts in the city of Zurich, 2000 and 2018.

Figure 4: Proportion of adults aged 25-65 with compulsory schooling only or less, by statistical zone and school district in the city of Zurich, 2000 and 2010-2018.

Note: 1 = Zurichberg school district, 2 = Uto school district, 3 = Waldberg school district, 4 = Glattal school district, 5 = Letzi school district, 6 = Limattal school district, 7 = Schwamendingen school district

Figure 5: Proportion of non-Western foreigners by statistical zones and school districts in the city of Zurich, 2000 and 2010-2018.
In the mentioned thematic issue of Hochparterre, mixing opportunities for schools are mainly seen in private and non-profit housing construction and in urban and neighborhood planning, with schools contributing to the attractiveness of the location by providing suitable teaching in a diverse environment and by opening up to the neighborhood (keyword 'Bildungslandschaften') and bringing their interests into the planning processes. Indeed, our spatial analyses (not reported here) indicate that the segregation of socially weaker population groups (often with a migration background) is significantly related to the availability of affordable housing. Although housing rents have doubled since 1990, urban districts 4 and 12 remain relatively affordable. Spatial differences are smaller for the lower-priced nonprofit housing. With around 25 percent, its share in the city of Zurich is relatively high compared with other Swiss cities and, according to a referendum, is to be increased to one-third by 2050. City-owned apartments play a smaller role, with the city itself dominating only in the already low-priced Hard neighborhood (district 4). Otherwise, the city relies largely on private housing cooperatives: Thanks to cost rent and assignment guidelines, they create housing in lower- and medium-priced locations and thus contribute to a certain mix. However, the fact that housing is provided by building cooperatives does not mean that it is comprehensively mixed according to social status and nationality, as the example of Friesenberg shows. This neighborhood, which is dominated by housing cooperatives, houses a predominantly Swiss middle class population.

Although targeted housing promotion and increased awareness of cooperative and private housing developers could increase neighborhood- and city-wide social and ethnic mixing, it is striking that the Hochparterre issue largely fails to mention the school itself with its spatial assignment practices. In the subsequent analyses of this study, not only the connection between residential and school segregation is examined in detail, but also explicitly the possibilities for greater mixing through small-scale adjustments of school catchment areas.

**Basel**

In Basel, too, there is a spatial differentiation of typical educational paths, both in 2000 and today (Figure 6). For a comparison, it must be noted that for the year 2000, due to the school system at that time, we can only distinguish the transfers from education year 9 to the Gymnasium (highest requirements) or to the school for professional education (Weiterbildungsschule). Nevertheless, common patterns can be identified for both points in time, but also clear deviations. For the year 2019, the high transfer rate to secondary level 1 (general requirements - lowest requirement level) in the north of Kleinbasel (north of the river) stands out. Compared to the year 2000, however, the ratio has completely reversed along the central river section of Kleinbasel. Thus, this part, together with the old town of Grossbasel (south of the river) and Bruderholz, has very low transfer rates to the lowest requirement level.

Although in Basel, as in Zurich, the proportion of adults with minimal schooling has declined significantly over the past decades, there is a strong - though not perfect - correspondence to the pattern of transfer rates for the composition of neighborhoods by social and cultural origin (Figures 6 and 7).
Bern

Throughout the canton of Bern, transfer to secondary school or Realschule usually takes place after elementary school, and the Gymnasium can only be attended after completion of the second year of secondary school. For this reason, only transfers to either secondary school or Realschule (lower requirements) are shown in Figure 9. As in Zurich and Basel, Figure 9 clearly shows the differences in the typical educational pathways depending on the school district. While more than half of all sixth-graders in the Bethlehem school district and just under half in Bümpliz transfer to the lower-level Realschule (darker areas in the western part of the city), the corresponding share is less than twenty percent in the Länggasse-Felsenau school district and less than fifteen percent in the Kirchfeld-Schlosshalde school district (lighter areas). These disparities can already be identified in 2009 but they have remained high in the last 10 years despite the objective of mixing (see the introduction in the chapter on the initial situation in the cities studied) or have even worsened when considering the Bethlehem and Kirchenfeld-Schlosshalde school districts.

In fact, it is notable that a large proportion of the darkly marked school districts in Figure 9 also have the highest number of people with low formal educational attainment (Figure 10) and non-Western nationality (Figure 11). Even though the share of adults with minimal educational attainment has decreased over the generations, the
concentration of people with non-Western nationality has remained unchanged in the area west of the city center towards Bethlehem and Bümpiz.

A change in typical school careers can be seen in the Breitenrain-Lorraine school district, where the proportion of transfers to secondary school has risen sharply and is now comparable to the Länggasse-Felsenau and Kirchenfeld-Schlosshalde school districts. This is explained by pronounced gentrification processes in this neighborhood, as reflected in the strong decrease of neighborhood residents with low educational attainment (Figure 10) and non-Western nationality (Figure 11). In the Bümpiz school district, the proportion of pupils transferring to the less demanding Realschule has also fallen, although it remains at a high level.

Figure 9: Transfers from public elementary school to secondary school types by school districts in the city of Bern, 2019

Figure 10: Proportion of adults aged 25-65 with compulsory schooling only or less, by statistical zone and school district in the city of Bern, 2000 and 2010-2018.

Note: 1 = Kirchenfeld-Schlosshalde, 2 = Mattenhof-Weissenbühl, 3 = Breitenrain-Lorraine, 4 = Länggasse-Felsenau, 5 = Bümpiz, 6 = Bethlehem

Figure 11: Proportion of non-Western foreigners by statistical zones and school districts in the city of Bern, 2000 and 2010-2018.
Geneva

In the city of Geneva, transfers from public elementary school to secondary school types are not shown spatially, but according to linguistic and social background, as the canton did not provide us with education statistics broken down by school districts or neighborhoods. Figure 12 shows that foreign-language students more often attend lower-level secondary schools and that the transfer rate to the secondary school type with high requirements is around twenty percent lower. The situation is similar regarding social background. For example, the transfer rate to secondary schools with high requirements is almost 30 percentage points higher for children of executives than for children from modest or underprivileged backgrounds (see Figure 12).

![Figure 12: Transfers from public elementary school to secondary school types by linguistic and social background, 2017.](image)

Figures 13 and 14 show that the share of people with low formal education (Figure 13) and non-Western nationality (Figure 14) varies mainly at the level of larger sectors, even if the evaluation was made at the level of fine subsectors (sous-secteurs). In 2000, this part of the population was concentrated on the western lakeshore as well
as on the southwestern part of the city. Since then, there has been a significant upgrading in the center, with relocation of the most socially strained neighborhoods to the southern outskirts. It can be assumed that the transfer rates to the higher requirement levels will be lower in these remaining focus areas, where composition effects described above are likely to play a role here in addition to individual factors.

Figure 13: Proportion of adults aged 25-65 with compulsory education only or less, by statistical subsector (sous-secteurs) and school district in the city of Geneva, 2000 and 2010-2018.

Note: 1 = Plainpalais Jonction, 2 = Pâquis Sécheron, 3 = Eaux-Vives Cité, 4 = Grottes Sain-Gervais, 5 = Acacias Bâtie, 6 = Saint-Jean Charmilles, 7 = Servette Petit-Saconnex, 8 = Champel

Figure 14: Proportion of non-Western foreigners by statistical subsectors (sous-secteurs) and school districts in the city of Geneva, 2000 and 2010-2018.

Lausanne

For the analyses of the city of Lausanne, only the core city was considered, excluding plateaus of the Jorat in the northeast and the exclave northwest in the Vernand area. In contrast to the other cities, Lausanne shows a less spatially differentiated picture with respect to typical educational paths, especially for the year 2000. In Figure 15, this is visible both by the similarly colored areas (depicting the proportions of transfers to the most demanding secondary level) and the bar charts, which do not diverge too much. Currently, the greatest variance is evident between the Belvédère secondary school district in the southwest (approx. 35%) and the Élysée secondary school district in the southeast (approx. 20%); however, within the dark-colored school districts, the much higher numbers in certain neighborhoods are likely to be masked due to the socio-spatial differences within the school districts.
(Figures 16 and 17). Otherwise, a considerable increase in transfers to the Progymnasium level can be seen today compared to 2000, especially in the areas of Centre, Florimont/Chissize and Sébeillon/Malley. Similarly, Figures 16 and 17 show a decrease in the proportion of the population with low formal education (Figure 16) and non-Western nationality (Figure 17) in these areas.

Figure 15: Transfers from public elementary school to secondary school types by secondary school districts in the city of Lausanne, 2000 and 2019.

Figure 16: Proportion of adults aged 25-65 with compulsory schooling only or less, by statistical subsector (sous-secteurs) and secondary school district in the city of Lausanne, 2000 and 2010-2018.

Note: 1 = Belvédère, 2 = Bergières, 3 = Béthusy, 4 = C. F. Ramuz, 5 = Elysée, 6 = Isabelle-de-Montolieu, 7 = Villamont

Figure 17: Proportion of non-Western foreigners by statistical subsectors (sous-secteurs) and secondary school districts in the city of Lausanne, 2000 and 2010-2018.

Since statistical subsector data were not provided by either the City of Lausanne or the Canton of Vaud, the subsectors used in this analysis are based on digitized sous-secteurs.
Winterthur

For Winterthur, like for the city of Lausanne, Figure 18 does not show a very pronounced spatial differentiation regarding typical educational paths. This is also consistent with the spatial distribution of the population with low formal educational attainment (Figure 19) and foreign nationality (Figure 20), which is largely concentrated in certain regions within the respective school districts. Accordingly, data on transfers by neighborhood would have been more informative here than data on school districts. Nevertheless, the highest transfer rate to the Gymnasium is to be found in the Stadt-Töss school district, while in the Veltheim-Wülflingen and Seen-Mattenbach school districts there are higher proportions of transfers to secondary schools with lower requirements (secondary levels B and C).

Figure 18: Transfers from public elementary school to secondary school types by secondary school districts in the city of Winterthur, 2000 and 2018

Figure 19: Proportion of adults aged 25-65 with compulsory schooling only or less, by statistical neighborhood and school district in the city of Winterthur, 2000 and 2010-2018.

Note: 1 = Oberwinterthur, 2 = Seen-Mattenbach, 3 = Stadt-Töss, 4 = Veltheim-Wülflingen
Preliminary conclusions

The present chapter first reviewed the findings on educational inequality in Switzerland in terms of unequal access to education depending on individual background and the composition of the school or class attended. The relative influence of individual characteristics and school composition was illustrated by analyses on reading/language achievement (PISA, Zurich Learning Survey). Not only is the composition effect (composition of school or class) particularly pronounced in Switzerland. Also, the confirmed tipping effect, according to which the composition only exerts a negative effect on reading achievement above a certain threshold, is highly relevant. Specifically, it was shown that a drop in school performance only occurs when the proportion of pupils with foreign-language or educationally disadvantaged backgrounds reaches around 30 or 40 percent, while performance fluctuations in schools or classes below this threshold cannot be attributed to school composition. This finding, confirming earlier studies, is of high political relevance, since it means that attention must be paid to the roughly 25 percent of urban schools with elevated concentration values. This holds not only for compensatory measures but also for school mixing, at least when it comes to compensating for the disadvantage in academic performance resulting from composition. The finding is also politically relevant, however, because it allays the fears of numerous middle-class and better-off and well-integrated parents that mixing would be at the expense of their children’s school performance. If schools can be mixed in such a way that the proportion of foreign-language or educationally disadvantaged pupils in all schools can be reduced below the threshold of 40 or 30 percent, this will lead to greater educational equity for today’s multiply disadvantaged pupils without disadvantaging the other pupils.

In addition, for the cities studied we showed how unequal access to education affects the typical educational paths depending on the school district or neighborhood. The differences in transfer rates regarding the respective lower-requirement secondary school types are particularly pronounced in Basel, Bern and Zurich. In northern Kleinbasel, the corresponding proportion is around 45 percent, compared with around 1 percent in Altstadt and Bruderholz. In Bern’s Betlehem school district, the average ratio is 65 percent, compared to around 15 percent in the Kirchenfeld-Schlosshalde school district. In Zurich, the average rate in the Schwamendingen school district is around 40 percent, compared to around 5 percent in the Zürichberg school district. No spatially aggregated data are available for Geneva, but the different rates shown according to linguistic and socio-professional background as well as the corresponding socio-spatial maps also suggest significant differences between, for example, the Acacias Bâtie school district and the Plainpalais Jonction school district. In Lausanne, the differences between school districts are less pronounced, with 35 percent transferring to the least demanding secondary schools in the Belvedère school district compared to 20 percent in the Elysée school district. The same is true for Winterthur, with corresponding proportions at 45 percent in the Seen-Mattenbach and Veltheim-Wülflingen school districts, compared to 30 percent in the Stadt-Töss school district. For both Lausanne and Winterthur, however, it is important to emphasize that due to the socio-spatial differences within the school districts, the differences in the
transfer rates depending on the neighborhood are severely underestimated. The extent to which the composition of the schools within the school districts differs in all cities will later become readily apparent from the reported concentration values in Module 1 and in greater detail in Module 2.
International research on school segregation

The spatial segregation of people from different socioeconomic backgrounds and ethnicities is increasing, and this observation is particularly true for cities and metropolitan areas due to migration (Tammaru et al. 2016). In addition to global, regional and national migration flows, segregation is also reinforced by increasing social polarization as well as societal processes of segmentation by social status and individual lifestyle. In fact, segregation processes can be observed not only in the place of residence, but also in other life-world contexts, such as education, work, or leisure time, which means that individuals hardly come into contact with the diversity in the everyday life of the general population anymore (Boterman and Musterd 2016). At the same time, residential segregation affects not only these spheres of life, but also all administrative decisions related to place of residence: the determination of political constituencies, school catchment areas, hospital catchment areas, the distribution of public transport stops, and many other administrative decisions. In the following, an overview of the research on school segregation will be given, followed by a discussion of the effect of fixed school catchment areas and their possible optimization to increase segregation.

School segregation in the U.S. and Europe

Research on school segregation took its roots in the United States. The landmark decision was the 1954 federal court ruling in Brown v. Board of Education, wherein historical segregation in public schools based on race was ruled unconstitutional. As a result, strict racial segregation was abolished in the southern states, and the southern schools became the most integrated region in the United States through the 1970s and 1980s, following state-mandated desegregation plans. However, since the 1990s, there has been a renewed increase in school segregation, particularly for African Americans and Latinos, attributed primarily to increased residential segregation and the expiration of court-ordered plans (Frankenberg et al. 2019). The effect of school segregation in the U.S. is exacerbated by highly unequal funding, as school districts are typically funded through local property taxes and school district boundaries often separate better-off neighborhoods from resource-poor areas. Although states should provide equal funding, the disparities between “white” and “non-white” school districts remain enormous. Indeed, a majority of U.S. residents consider school segregation a pressing problem. While the use of school busing to mix across school districts, introduced in the mid-1970s, remains controversial today, majorities favor other measures to increase mixing. These include the establishment of new cross-district public schools with special curricula (“magnet schools”), increased social housing construction also in better-off neighborhoods and suburbs, and the strategic adjustment of school district boundaries to create more mixed school districts.

Of course, it is legitimate to ask whether an equalization of unequal schooling conditions can be achieved without social mixing. If the "composition effects" mentioned in the introduction can be compensated just as well by adjusting resources (supervision ratio, physical condition of schoolrooms, teaching materials), social and ethnic segregation need not be regarded as a problem in itself (Rumberger and Palardy 2005). However, resource allocations cannot replace the "peer effects" (Coleman 1966) which can be achieved by the presence of pupils with a greater affinity for education. In addition to pro-education attitudes, values, behaviors, and the beneficial learning effects from interactions among pupils, research also emphasizes teachers’ expectations and instructional styles that correlate with the composition of schools, as well as the self-selection of qualified teachers into less stressed schools. In interaction, peer effects and teacher expectancies can affect relationships between teachers, children, and parents, cause classroom disruptions, and violence among children and youth. Even if additional resources are directed toward adjusting selected school characteristics, greater mixing of schools appears to be a more effective and also less costly measure, supplemented if necessary with resource allocations (vgl. auch Palardy 2013).

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6 https://edbuild.org/content/23-billion#CA (accessed 10/17/19)
The issue of segregation between schools has also gained prominence in Europe in recent years. Recent studies have demonstrated increasing school segregation in various cities (Boterman 2013; Maloutas and Ramos Lobato 2015; Bernelius and Vaattovaara 2016; Casey 2016). This is associated in individual countries with the introduction of free school choice, but also with the increasing influx of private schools - although free school choice or even the admission procedure and financing of private schools is regulated to a greater or lesser extent depending on the country. Nevertheless, in the OECD area, assignment by local or regional school authorities through catchment areas remains widespread (Sydänlammi 2019). Thus, in these countries, the focus is on catchment areas, whose shape reproduces the increasing residential segregation to a greater or lesser extent.

**Effect of school catchment areas**

The extent to which school catchment areas reproduce residential segregation was first examined by comparing the social and ethnic composition of schools with the composition of residential districts (selected age group from census data). This involved the estimation of indices established in segregation research (dissimilarity, isolation) for different population groups with regard to schools, and comparing the respective values with regard to residential districts (e.g., Burgess, Wilson, and Lupton 2005; Johnston et al. 2006). Studies interested in the effect of free school choice used spatial data on school catchment areas collected for the first time in the U.S. and compared the composition of the schools with the composition that would result from consistent attendance at the neighborhood school according to the catchment area (selected age group from census data; Saporito and Sohoni 2006; Sohoni and Saporito 2009). However, the focus there is on composition bias due to free school choice, with school catchment areas inaccurately equated with school 'neighborhoods'. This assumption is problematized by Meredith Richards (2014), who has recognized that both residential districts and school catchment areas are based on artificial, administratively imposed boundaries. In particular, she notes irregular forms of school catchment areas that point to a strategic adjustment of catchment areas for the purpose of ethnic segregation. Despite elements of free school choice (cross-district "magnet schools," privately run "charter schools"), four-fifths of pupils in the U.S. still attend the public school in their neighborhood. Richards thus focuses her investigation on the design and segregating effect of the catchment areas themselves.

By talking about the 'gerrymandering' of school catchment areas, Richards specifically refers to the phenomenon of manipulating the shape of political constituencies in U.S. states to the advantage of the ruling party. In this context, the term 'gerrymandering' was coined as early as the beginning of the 19th century, inspired by the salamander-like shape of a newly drawn electoral district under then Governor Elbridge Gerry. Accordingly, 'gerrymandering' in the context of electoral districts in the U.S. is also the most studied area in the field of strategic determination of administrative districts, with the resulting distortion in representation of the population occupying the American courts to this day. In this context, thanks to data availability and with increasing computing power, algorithms are also used, with opposite intentions. On the one hand to maximize the distribution of seats in favor of the ruling party, on the other hand to uncover blatant cases of party-politically motivated distortions. For the latter purpose, thousands of maps with alternative district apportionments were generated, evaluating their representativeness in comparison to the valid district map (Liu, Cho, and Wang 2016; Tam Cho and Liu 2016). In order to identify any 'gerrymandering' in school catchment area design as well, Richards (2014) accesses an expanded national database that collects voluntarily-submitted spatial data on catchment areas, covering about 40 percent of all U.S. public schools. She compares the ethnic composition of schools as determined by the applicable catchment areas (selected age group from census data) with the composition of schools that would result if children and adolescents were assigned to the nearest school (air distance) in a 'natural' way, i.e., in the absence of 'gerrymandering' bias. Although the 'neighborhoods' of schools elicited in this way do not account for geographic obstacles such as busy roads or rivers, the comparison between catchment areas and such neutral 'neighborhoods' can nevertheless provide indications of whether, in aggregate, there is 'gerrymandering' towards segregated schools in a particular school district. Indeed, Richards shows that in the U.S., most schools' applicable catchment areas are somewhat more segregated than their spatially defined 'neighborhoods,' especially in school districts that have
experienced large demographic changes. Conversely, she also shows that in a minority of school districts, irregular forms of catchment areas purposefully serve to increase school mixing, particularly in those school districts that have been court-ordered to adopt mixing measures (cp. also Richards 2017). Another study brings evidence for the integrative performance of irregular catchment areas, while casting doubt on the ‘gerrymandering’ of segregated catchment areas observed by Richards (Saporito and Van Riper 2016). Like Richards, however, these authors see small-scale adjustment of catchment boundaries as the most effective mechanism for ensuring a degree of ethnic integration in larger, ethnically and socially diverse school districts.

**Optimization of school catchment areas**

The idea of using algorithms to optimize administrative district boundaries emerged as early as the 1960s, with the beginnings of mathematical theory on artificial intelligence. In addition to research on the optimization of voting districts, which has dominated to this day, studies on the optimization of school catchment areas emerged early in the U.S. (Clarke and Surkis 1968; Heckman and Taylor 1969). Even though automation aimed at a certain objectification of boundary drawing, which to this day is often done manually based on local knowledge, intuition and subjective insights, it was clear from the beginning that boundary drawing would remain a fundamentally political process. In addition to the required political objectives and criteria for the algorithm, in reality there is not one unambiguously optimal solution, but the different criteria open up a large space of possibilities. In this respect, the algorithm is not intended to replace human influence, but to be understood as an auxiliary tool for decision-making by showing alternative possible solutions and their costs and feasibility (Heckman and Taylor 1969). In doing so, qualitatively different solutions for school assignment should also take different positions with regard to manifold conflicting goals (desJardins et al. 2007). It is also clear that the objectivity and fairness of the automated process depends not only on the targets, but also on the ability of the algorithm used to adequately capture real-world phenomena and the given criteria. Even though today’s data, computing power, and optimization techniques allow for much more comprehensive and efficient evaluation of a wide variety of realistic options, automated solutions will continue to rely on human post-processing (Ferland and Guénette 1990). It is conceivable, however, that machine learning techniques will be used to capture manual post-processing and anticipate it in future solution proposals (Sydänlammi 2019).

Historically, school catchment areas have typically been oriented toward the goal of ensuring the shortest and safest routes to school. Although school catchment areas change frequently due to fluctuations in year groups as well as settlement development, these changes are ideally limited to children in the year of enrollment to avoid too frequent changes over their school careers (desJardins et al. 2007). Caro et al. (2004) for their part, suggest the following desirable characteristics of catchment areas:

1. Each block or neighborhood is assigned to exactly one school.
2. School assignments shall not exceed the existing capacity of the schools.
3. Catchment areas must be contiguous.
4. Catchment areas must not cross railroad tracks, rivers or roads with heavy traffic.
5. School routes are minimized, with no single school route exceeding a certain maximum length.
6. If settlement blocks must be divided, then the same grades should still go to school together.
7. New plans must bear some resemblance to previous plans, with annual changes remaining moderate.

Less importance is placed on the compactness of the resulting school catchment areas, in contrast to optimization for political constituencies. Moreover, Caro et al. concede that the need for contiguous areas may conflict with the goal of ethnic mixing. Indeed, in the United States, court-ordered mixing plans have explicitly waived this requirement. Similarly, Bouzarth et al. (2018) in their optimization of school assignments, demonstrate a fundamental trade-off between distance and social mixing. Accordingly, in certain optimization studies, both
compactness and contiguous catchment areas are dispensed with (Clarke and Surkis 1968) or alternatives are presented that give different weights to the conflicting goals (desJardins et al. 2007). Although 'exact' optimization algorithms that consider the entire possibility space have also been proposed for optimization experiments, heuristic methods have prevailed due to the nearly infinite possibility space for real-world conditions (Sydänlammi 2019). Although these are not able to find the absolute optimal solution with certainty, they can develop solutions that are clearly superior to the previous feed-in plans. Especially established are local search algorithms, which assign smaller spatial units to certain constituencies or catchment areas in an iterative procedure until no further improvement occurs ('local' optimum). If the existing plan is taken as the starting point for the iterations, this is the best way to ensure a certain coherence with previous plans (point 7 in the preceding list).

Following previous studies (Caro et al. 2004; Bouzarth et al. 2018), the present study uses a single variable for the objective function to be optimized, while other criteria (safe routes to school, distance, capacity of schools) are considered as constraints. In particular, we are guided by a prototype algorithm developed by Hertta Sydänlammi (2019) for the context of Helsinki, which explicitly targets convergence of schools in terms of their composition by linguistic background.

Compared to the prototype of Sydänlammi (2019) we have significantly enhanced the algorithm to allow the generation of realistic alternative catchment areas taking into account actual reasonable school routes. While the Finnish algorithm is based on spatial grid units of 250x250 meters and uses air distance for maximum school routes, the present study uses small-scale street blocks as modeling units and simulates safe individual school routes along a comprehensive pedestrian network. In addition to busy roads and dangerous road crossings, spatial obstacles such as rivers and forests are also considered. Moreover, the variable to be optimized is not only the composition of schools by linguistic background, but an index is used which additionally accounts for the educational background of parents. Moreover, the area swaps tested for optimization are not tested in random order for individual schools, but convergence is achieved by a systematic sequence of the catchment areas to be optimized - starting with the schools with the least balanced composition. Also, more sophisticated area swaps are considered in our search algorithm. While the algorithm for Helsinki checks optimization by adding a neighboring spatial unit in each iteration, an extended spatial horizon is considered in our algorithm (repeated combinations of adding and dropping up to two neighboring units each). The exact procedure is described in more detail in the data and methods section below and in the appendix.
Data and methods

The analyses in this study are based on data from the last census in 2000, supplemented by data from the annual structural survey (samples), which replaced the decennial census in 2010. In addition, for the chapter on unequal access to education in Switzerland, data from the Zurich Learning Survey and the national PISA 2000 dataset were used, supplemented by city-specific data on transfer rates from elementary school to various types of secondary school based on cantonal education statistics (Basel, Geneva, Lausanne, Winterthur, Zurich) or data provided by the school authorities (Bern).

The focus is on the older 2000 census data, both for the study of school and residential segregation and for the optimization of catchment areas, since this was still a full census, which thus also contains data on all school-age children and their parents in the 2000/01 school year. Since we did not have any internal data from the school authorities for the study presented here, we were left with the evaluation of the older census data as a suitable way to investigate the relationships of interest and the potential for optimization in school assignment (cf. explanations on data availability in the appendix). Since no data on school catchment areas were available for 2000/01 either, these had to be reconstructed at considerable expense based on the census data.

The following sections describe the methodological procedure for reconstructing catchment areas for the first time in Switzerland, based on the 2000 census data. This is followed by a description of an index for social and ethnic concentration, which forms the basis for determining the relationship between residential and school segregation and at the same time represents the central optimization variable for the algorithm. In the catchment area optimization section, the novel, detailed algorithm developed is explained. Furthermore, we list the interview partners from the cities of Bern, Winterthur and Zurich, who contributed to the qualitative part of the study.

Pupils and reconstruction of catchment areas 2000/01

Figure 21 provides an overview of how the 2000 census data were used in our analyses. From the census, lower primary school pupils were taken into account (assignment according to the cutoff date for school enrollment of the respective city in 2000), since the first years of schooling are crucial for individual educational achievements (Moser et al. 2011). Depending on the city and school system, different class levels were used.\(^8\) A detailed compilation can be found in the explanations on the identification of the lower school pupils in the appendix. A restriction to the 1st graders who were newly assigned to a school for the school year 2000/01 was not made, since the 1st graders could not be safely identified with the help of the data basis (assignment according to cutoff date). In addition, the increased number of cases makes it possible to determine the actual catchment areas more reliably and to estimate their social and ethnic composition more reliably.

For the reconstruction of the catchment areas, different data sources were available for the cities studied. If not already available as a statistical unit, existing statistical units were first divided into small-scale street blocks (called parcels in the following text).

Based on available census information on the school attended by the identified pupils, a multistage procedure was used to assign the corresponding parcels to each school (see green arrows in Figure 21 and more detailed explanations on parcellation and reconstruction in the appendix).

\(^8\) In the German-speaking cities of Switzerland and Geneva, 1st-3rd graders were included. In Lausanne, kindergarten children and 1st-2nd graders were taken into account, since kindergarten is attended at the school location and thus a larger sample was achieved. For more information, see the chapter Census Data 2000: Identification of Lower School Students and Attribution of Foreign Language Proficiency and Parents’ Educational Background in the appendix.
Concentration indices for schools and 'neighborhoods'

To map school segregation in the 2000/01 school year, we used individual characteristics of the identified lower school pupils regarding foreign language and the educational background of the parents, and we calculated a 'concentration index' at the level of the parcels (cf. blue arrows in Figure 21). This corresponds to the mean value of two proportions:

\[
\text{Concentration index} = \frac{\% \text{ foreign language} + \% \text{ low educational background}}{2}
\]

Thus, our concentration index is based on the relevant findings that the composition effects found in Switzerland are due to composition by linguistic and socioeconomic origin (Erzinger, Jäger-Biela, and Hauser 2019; cp. OECD 2016). Foreign language refers to the fact that German or German dialect or, in the case of Geneva and Lausanne, French was not indicated as the language spoken at home.

The low educational background for calculating the 'concentration index' is defined in such a way that no identified parent (compare method for identifying parents in the appendix) has an educational qualification beyond compulsory schooling.

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\(^9\) Compare ‘Mixed Index’ within the QUIMS program by the education department of the canton of Zurich: Mean proportion of foreign speakers + foreigners.
Figure 22 shows a choropleth map with the resulting concentration values on parcel level for the city of Zurich. To map the segregation between schools, these parcel values are aggregated at the level of the reconstructed catchment areas by means of a weighted average (see chapter Module 1).

To reflect residential segregation, a concentration index was calculated for each school 'neighborhood'. The school "neighborhoods" are defined in such a way that the pupils are assigned to the school that is located closest according to the air distance. With the definition by air distance, the school 'neighborhoods' correspond to so-called Voronoi\textsuperscript{10} diagrams, whose shapes and resulting concentration values for the city of Zurich are shown in Figure 23. Thus, the distribution of concentrations based on catchment areas (school segregation) can be compared with the distribution that would 'naturally' result based on residential segregation (see Module 1 chapter). This method is based on Richards' (2014) seminal analysis of school and neighborhood segregation in the U.S. (see chapter international research on school segregation).

\textsuperscript{10} Also called Thiessen polygons or Dirichlet decomposition.
Optimization of the catchment areas 2000/01

To investigate the extent to which there is room for maneuver for school authorities to achieve greater mixing, alternative catchment areas were simulated using a Java-based algorithm. The aim is not to allocate individual pupils, but to develop proposals for adjusting catchment areas along their boundaries. The catchment areas remain contiguous and walking distances to school remain short and safe (principle of "neighborhood school", no school transport). This novel, detailed algorithm is parameterized and therefore allows simulations under different conditions. In particular, the algorithm allows to compare different scenarios, such as allowing the longest school route within the catchment areas to be exceeded by a certain percentage, or the previous school utilization to be exceeded or undercut by a certain percentage.

The starting point for the algorithm is the previously allocated school per parcel, its concentration index, and the identified pupils, letting us simulate the resulting individual school routes depending on the assignment. Likewise, the algorithm for the optimization of the catchment areas is based on these values by calculating a hypothetical new concentration index per school for each boundary adjustment of the catchment areas. For the simulation of the school routes, additional geodata are consulted (OpenStreetMap, forest areas according to swisstopo, "National

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11 At this point we would like to thank Marcel Rieser, PhD, expert for traffic simulations of the company Simunto GmbH, for the Java-based implementation of the algorithm including the preparation of the pedestrian network and the traffic load data for the simulation of the individual school routes.
Passenger Transport Model NPVM\textsuperscript{12}. The simulated individual school routes represent realistic school routes, avoiding footpaths along busy roads or forest sections. For routing school routes, such sections are multiplied by a length factor so that such routes are bypassed by safer routes whenever possible. Figure 24 shows the length factors assigned to streets for the case of Zurich. In addition to these factors, a fixed penalty is assigned for routing at identified crossings of streets with heavy traffic (without an overpass or underpass and without a suitable crossing), depending on the danger of the crossing. This categorization of crossings is illustrated with colored points in Figure 24. The maps of pedestrian networks and avoided busy roads and forest paths for the other cities studied can be found in the chapter on pedestrian networks in the appendix.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure24.png}
\caption{Footpath network and avoided busy roads and forest paths in the city of Zurich (2019).}
\end{figure}

Notes: Footpath network including pedestrian overpasses and underpasses colored in gray (OpenStreetMap, 2019) and roads with heavy traffic considered in red (here: MATSim traffic model of IVT ETH Zurich, 2019; in the other cities "National Passenger Traffic Model NPVM") as well as paths through forests (geodata © swisstopo: Vector 200 Land Cover, 2017), whose sections are multiplied for routing with a length factor for the simulation of individual school routes. A penalty is added for crossing busy roads (without an overpass or underpass). No penalty lump sum is added in case of overpasses and underpasses (Geomatik + Vermessung Stadt Zürich, 2019).

For the simulation of alternative catchment areas, an algorithm is used to search for local optima (‘hill-climbing’). Starting from the valid catchment areas, an attempt is made to adjust the catchment area for each school in such a way that its own ‘concentration index’ is brought as close as possible to the citywide average, but the area should remain contiguous. The optimization procedure can be compared to a board game, in which the schools try to swap parcels (small-scale street blocks) in the best possible way, so that their own ‘concentration index’ is as close as possible to the city average. In one turn, the own catchment area can be extended by 0 to 2 neighboring parcels.

\textsuperscript{12} For the simulations of the city of Zurich, the MATSim traffic model of the IVT/ETH was still used, since the NPVM was not yet available at the time of publication of the pilot study. In addition, in the case of the city of Zurich, the road network could be supplemented with safe school crossings according to the school instruction (Geomatik + Vermessung Stadt Zürich, 2019), as this data was made available. Furthermore, adjustments were made during the in-depth study, such as the sorting of candidates based on the absolute deviation of the expected ‘concentration index’ as well as an improved identification of neighborhoods for the variant with the interpenetrating catchment areas.
School mixing: more equity through intelligent school zoning

(‘take’), and at the same time, 0 to 2 own edge parcels can be given away to a neighboring school (‘give’) in the same turn. The game starts with the school that has the largest deviation from the city average. This school makes further moves until no further approximation to the city average is possible. After that, the schools are ranked according to the newly calculated concentration values to find the next school to make a move. If no further optimization is possible for the schools with the highest deviations from the city average, it is the turn of the schools with somewhat lower deviations, so that in the course of the game it is also the turn of schools with average concentration values. The following criteria apply to the moves of all schools:

- Involved parcels must meet the following conditions; (i) the maximum existing school route length in the catchment area of each school affected by a move must not increase by more than the specified percentage, (ii) the catchment areas of all schools affected by the move must remain contiguous, (iii) the maximum school capacities must not be exceeded as a result of the changes, (iv) none of the participating neighboring schools must be further away from the mean at the end of the move than at the beginning of the move, if it is already further away from the mean at the beginning of the move than the trading school, (v) none of the neighboring schools involved in the action may have its ‘concentration index’ increase by more than 7 percentage points if this brings it to a value of more than 40%, (vi) the concentration index of the trading school comes closer to the mean as a result of the parcel swap, and (vii) no pupil has to pass another school during this swap (min. 50m distance), unless it is an immediately adjacent school (max. 125m from the place of residence).

For the final selection of the parcel candidates involved in the move, the possible and admissible moves are sorted based on the absolute deviation of the expected ‘concentration index’ of the candidates from the mean value of the concentration index. If two candidates score equally well with respect to the expected concentration index, the school with the largest distance from the mean is searched among the schools affected by the candidates and compared with which candidate it approaches the mean the most. In the list sorted in this way, the first list item then represents the candidate with the greatest potential for improvement. This candidate is then returned as the best solution by the algorithm and implemented as a move. Tabular and spatial data for the individual simulation steps are generated as output for the configurable parameters length of the school route and school capacity. In the future, the algorithm described above could be transformed into an auxiliary tool to support school assignment and school space planning.

For the preparation, recoding, analysis and presentation of the data, we use the geographic information systems QGIS and ArcGIS, as well as the statistical software R.
Module 1: Relationship between residential and school segregation

Zurich (pilot study)

To relate residential and school segregation, we rely on the approach of Richards (2014) and compare the composition of schools resulting from the applicable catchment areas with the composition of the schools' 'neighborhoods' defined via the Voronoi diagrams (shortest air distance to the schools). In our case, the prerequisite was to first reconstruct the catchment areas based on the 2000 census data (see data and methods chapter). The elicited catchment areas of the lower schools are presented in Figure 26. Based on these catchment areas, we were able to aggregate parcel level concentration indices (see Figure 25, left) to the school level and compared with the concentration indices for the associated school 'neighborhoods' (see Figure 25, right).

Figure 25: Choropleth map of parcels (left) and school 'neighborhoods' (right) in the city of Zurich (2000/01), see notes to Figures 22 and 23.

Figure 26: Map showing the reconstructed catchment areas for the city of Zurich (2000/01).
For his comparative studies of U.S. school districts, Tomas Monarrez (2019) chose a visual representation format, which we replicate for the city of Zurich. Here, the scatter plot in Figure 27 shows for each school (bubble) the calculated hypothetical concentration index according to 'neighborhood' (horizontal axis), as well as the actual concentration index for the school resulting from the applicable catchment area (vertical axis). The size of the bubble indicates the capacity of the school (number of assigned pupils).
concentration index in their catchment area. Thus, the schools would be on a steeper regression line compared to the 45° line. Conversely, a school community whose catchment areas are specifically designed to balance out the schools would have a flatter regression line: the differences between the 'neighborhoods' (horizontal axis) are balanced out to some extent by the layout of the catchment areas and the differences in the resulting concentration indices of the schools (vertical axis) are less pronounced.

The blue regression line in Figure 27 indicates that lower schools in the city of Zurich reflect on average the composition of their 'neighborhood'. Thus, the effect of residential segregation is neither exacerbated nor mitigated. Although the concentration at certain schools is over- or under-proportional in relation to their 'neighborhood', most schools are relatively close to the 45° line. Since in the city of Zurich the school districts are responsible for determining the catchment areas, we also conducted the evaluation separately for the individual school districts. An increase in residential segregation could only be shown for the school district Schwamendingen in the school year 2000/01. For a discussion of the correlations in this and other school districts, we refer to the corresponding section in the following chapter on the second module, where we also discuss the potential for optimization at the school district level.

**Basel**

Similarly, we were able to reconstruct the catchment areas of the lower schools for Basel (Figure 29) and to put aggregated concentration values per catchment area in relation to the concentration values of the respective school 'neighborhoods' (Figure 28, right). For Basel, too, we find that residential segregation is largely reproduced in terms of school composition in school year 2000/01 (regression line with 45° angle, Figure 30). As in Zurich, a strong dispersion in the concentration values can be observed depending on the catchment area or neighborhood, with the highest measured concentration value here being 60 rather than 70 percent. For the dispersion of the concentration indices within the school districts, we again refer to Module 2.

![Figure 28: Choropleth map to parcels (left) and school 'neighborhoods' (right) of the city of Basel (2000/01).](image-url)
Figure 29: Map showing the reconstructed catchment areas for the city of Basel (2000/01).
In the 2000/01 school year, Bern also shows a large disparity in the concentration values of the school neighborhoods (Figure 31, right), which is also reflected in the composition of the lower schools (Figure 33) according to the reconstructed catchment areas (Figure 32). The values for the catchment areas (vertical axis) show values of up to 50 or 60 percent, although most schools have values below 40%. In Bern, too, segregation between residential areas was largely reproduced in the schools when considering the catchment areas at that time (regression line with 45° angle, Figure 33).
Figure 33: Scatter plot of the relationship between residential and school segregation in the city of Bern (2000/01).

Geneva

The evaluations of the reconstructed catchment areas (Figure 35) at the lower school level in the 2000/01 school year indicate less dispersion between schools and between school neighborhoods for Geneva (Figures 34 and 36) compared to Zurich, Basel and Bern. The maximum concentrations here range around 50 percent. Unlike for Zurich, Basel and Bern, Geneva’s catchment areas appear to show a slightly dampening role on residential segregation (regression line flatter than 45°-line, Figure 36). However, when considering the schools in neighborhoods with values of 35 percent or more (right edge), then their school catchment areas map the neighborhood composition one-to-one. A closer look, therefore, reveals that the flattened regression line occurs because the catchment areas appear to balance school compositions in neighborhoods with scores of 30 percent and below. This is evident from the slightly under-proportional concentration values (in relation to the respective school ’neighborhood’) in the middle range and several over-proportional concentration values at the left edge of the scatter plot. In this respect, the range of school concentration values remains large despite this selective equalization, with values between about 10 and 50 percent.

For more detailed analyses at the school district level, we refer the reader to the results for Module 2.
Figure 34: Choropleth map to parcels (left) and school 'neighborhoods' (right) of the city of Geneva (2000/01).

Figure 35: Map showing the reconstructed catchment areas for the city of Geneva (2000/01).
Lausanne

As in Geneva, the maximum concentration values of Lausanne’s lower-level\textsuperscript{13} schools in the 2000/01 school year are below 50 percent with one exception (Figures 37 and 39), whereby we again refer to the reconstructed catchment areas to the lower-level schools (Figure 38). From the minimally flatter slope of the regression line compared to the 45° line, a balancing effect of school catchment areas can also be stated in Lausanne. In particular, the flattening of the regression line is probably mainly due to one school on the right-hand edge with a strongly under-proportional concentration of disadvantaged pupils (in relation to the school’s ‘neighborhood’) and three schools on the left-hand edge with a strongly over-proportional concentration in some cases. Overall, large differences in the composition of schools and residential quarters can also be discerned for Lausanne.

The detailed analyses of the neighborhoods can be found in the chapter on Module 2.

\textsuperscript{13} In Lausanne, kindergarten children as well as 1st - 2nd graders were considered, since kindergarten is attended at the school location and thus a larger sample was achieved.
Figure 37: Choropleth map to parcels (left) and school ‘neighborhoods’ (right) of the city of Lausanne (2000/01).

Figure 38: Map showing the reconstructed catchment areas for the city of Lausanne (2000/01).
Winterthur

In Winterthur, too, the concentration values in the 2000/01 school year are at a lower level than in Zurich, Basel and Bern. Here, the maximum concentration value is just under 40 percent, while most schools back then show values between 10 and 30 percent (Figure 42). As in Geneva and Lausanne, the slightly flattened regression line compared to the 45° line suggests a certain equalizing effect of school catchment areas. In fact, for the school at the far-right edge of the scatter plot, there is a disproportionately low concentration compared to its ‘neighborhood’ (distance to the 45° line). The burden is even more under-proportional in a second school, which, however, is located in a neighborhood with a concentration value of only 30 percent (Figure 42). Consequently, in the case of Winterthur, a slightly reduced range in the school concentration values can be observed, but this is mainly due to a favorable catchment zone for one single school, whereas no systematic balancing can be discerned by means of the catchment zones of the remaining more burdened schools.
Figure 40: Choropleth map to the parcels (left) and school 'neighborhoods' (right) of the city of Winterthur (2000/01).

Figure 41: Map showing the reconstructed catchment areas for the city of Winterthur (2000/01).
Preliminary conclusions

In all cities studied, the composition of the school catchment areas reflects residential segregation to a largely unabated extent. The situation is only slightly modified in Geneva, where the observed equalization only affects the less burdened “neighborhoods” and more burdened school neighborhoods also go hand in hand with a correspondingly burdened school. In Winterthur, the layout of the school catchment area only leads to a certain equalization in the most burdened neighborhood, while no corresponding equalization can be observed for the other schools.

In addition, the analyses for all cities show large differences in the composition of both the ‘neighborhoods’ and the schools across the entire city. The highest range in the concentration values of schools in 2000 can be observed in Zurich, with values between 5 and 73 percent (cf. scatter diagrams). The second widest range is in Basel, with values between 7 and around 60 percent. This is followed by Berne, Lausanne and Geneva, where the range is rather between 0 and 50 percent, with one school each in Berne and Lausanne reaching the value of 60 percent. Finally, in Winterthur, the values in 2000 were between 5 and 40 percent. However, the differences between schools are also considerable within selected school districts, and here we refer to the more detailed analyses in Module 2. In view of the large differences between schools due to residential segregation, the question arises whether school authorities do have room for maneuver to achieve greater mixing. This question is addressed in the following chapter.
Module 2: Room for maneuver for greater mixing

The scope for school authorities to use catchment areas to contribute to greater mixing between schools can be assessed by contrasting the above evaluations of current catchment areas with evaluations based on alternative optimized catchment areas. In the following, we first conduct a city-wide analysis for the school year 2000/01 for each of the cities studied, then discuss the situation within the school districts, and finally venture a preliminary analysis on the school 'neighborhoods' in 2019/20. Due to the data situation, however, the optimization algorithm described in the methodology chapter is only run for the school year 2000/01.

Zurich (pilot study)

Optimization of catchment areas in the 2000/01 school year

We perform the stepwise optimization of the catchment areas based on the concentration values at the level of small-scale street blocks (Figure 25, left) and starting from the reconstructed catchment areas (Figure 26). Here, the algorithm sets the goal of approximating the concentration indices at the level of (adjusted) school catchment areas to the citywide mean. For the simulation of the realistic individual school routes and for the calculation of the individual school route lengths, the coordinates of the identified lower school pupils as well as the coordinates of the school assigned according to the catchment area are considered (see chapter data and methods). The school district boundaries are deliberately not considered in our optimization, which means that the optimized catchment area boundaries may also provide information about necessary adjustments to the school district boundaries. In addition to the maximum school route length per school catchment area, the capacity per school is considered in the optimization, whereby five scenarios with different margins are run through in these boundary conditions:

- Scenario A: Maintaining maximum school route length and capacity per school.
- Scenario B: Maintain capacity, increase maximum distance by a maximum of 10 percent
- Scenario C: Maintain distance, deviate from existing capacity by a maximum of 10 percent.
- Scenario D: Deviation from maximum distance and capacity by a maximum of 10 percent per school
- Scenario E: Scenario D with possible interpenetration of catchment areas ('diagonally' across road intersections and squares).

To leave some leeway for the optimization, a deviation of a maximum of five percent was also allowed in the scenarios with retention of capacity or distance, which means that area swaps are possible even in the smallest schools, which can lead to a capacity overrun of one child in the individual iterations and in the optimized solution compared to the initial situation. This deviation is considered negligible for the determination of the catchment areas, since even with the conventional determination of the catchment areas there is a need for manual adjustments to individual pupils. Figure 43 again shows the catchment areas we have reconstructed for the 2000/01 school year, but contrasts these with the optimized catchment areas according to the five scenarios described.

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14 The optimizations for the pilot study in the city of Zurich were carried out slightly differently than in the newly studied cities (see footnote in chapter data and methods). In particular, the MATSim traffic model was still used and safe school crossings according to the school instruction (Geomatic + Vermessung Stadt Zürich, 2019) were additionally considered. In addition, minor adjustments were made for the later studies, such as sorting candidates based on the absolute deviation of the expected 'concentration index' and improved identification of neighborhoods for the variant with interpenetrating catchment areas.
(0) Catchment areas 2000/01

(A) Optimization (max.dist. +5%, max.cap. ±5%)

(B) Optimization (max.dist. +10%, max.cap. ±5%)

(C) Optimization (max.dist. ±5%, max.cap. ±10%)

(D) Optimization (max.dist. ±10%, max.cap. ±5%)

(E) Scenario D with interpenetrating catchment areas
How do these optimized catchment maps fare in terms of the criteria of Caro et al. (2004; cp. chapter on international research)? The chosen optimization procedure ensures that 1) each street block is assigned to exactly one school, 2) the capacity limits of the schools are not significantly exceeded, 3) the catchment areas remain contiguous, 4) the catchment areas do not extend across roads with heavy traffic (or other obstacles such as rivers or railroad tracks), 5) the maximum school travel lengths per school are not significantly exceeded. In addition, 6) street block splits are not even foreseen in the present analysis. Finally, it can be seen 7) that most of the catchment areas remain recognizable in their form in all scenarios, except for single catchment areas, which become more extensive and less compact with increasing scope in terms of capacity and school travel distance. Regarding the last point, it should be noted that larger adjustments would result from the one-time switch from present to optimized catchment areas. If, as in the present study, several cohorts are accounted for in a continuous optimization, a similar consistency for follow-up years can be ensured as has been the case so far. Overall, the boundary conditions and the simulation of reasonable school routes ensure that the suggested adaptations are rather small-scale and feasible to implement.

Beyond these criteria, however, the optimizations have the central objective of contributing to the mixing between the schools as much as possible. The line diagram in Figure 44 illustrates the convergence process that occurs using the example of scenario A (maintaining capacity and maximum distance). The concentration indices of the schools converge toward the citywide mean value. The diagram shows that little can be done for individual schools in this scenario, as they remain at their relatively high or low concentration index. For most schools, however, considerable convergence occurs even in the restrictive scenario A.

The citywide equalization between schools becomes even more visible in Figure 45 with the resulting scatter plots for the different scenarios, where the first panel again reflects the initial situation with the reconstructed applicable catchment areas. In fact, the analysis shows that with the small-scale adjustments, some equalization between schools already arrives for scenario A, which manifests itself in a flatter regression line. Although individual schools take up different positions depending on the scenario (vertical axis: concentration value of catchment area), no clear added value from scenarios B to E becomes visible, at least in the present citywide consideration (similar slopes).

Even if the citywide balance can be perceived as modest, this has to do with the difficulty of mixing the spatially clustered schools with low concentration indices to a greater extent (bubbles in the left half of the scatter plots). In contrast, for the schools with initially high concentration values (above 40%), a significant decrease in these values can be observed, with few exceptions. In this respect, taking the above criteria into account, the optimization succeeds in significantly increasing the social and ethnic mix only for some of the schools. Even if mixing is desirable for all schools, a great deal would be achieved with greater mixing, especially in these schools with high social strain.
Figure 44: Development of the concentration index per school in the optimization process according to scenario A for the city of Zurich (2000/01).

Notes: The line diagram shows the development of the concentration index per school starting from the actual catchment area (point 0) over all iterations up to the optimized catchment areas according to scenario A (iteration 1094). In the legend, the schools are sorted by decreasing concentration index in the initial situation (point 0). The colors in the legend also match the maps in Fig. 43.
Module 2: Room for maneuver for greater mixing

Figure 45: Scatter plots of the relationship between residential and school segregation with comparison to different optimization scenarios in the city of Zurich (2000/01).

Note: For panel (0), see the explanations on Figure 27. In comparison, the other panels show how the schools position themselves in the corresponding scenarios A to E. The weighted OLS regression lines colored in red are flatter compared to panel (0), which corresponds to a leveling of the concentration indices of the individual schools (axis ‘catchment areas’). Furthermore, the size of the bubble indicates the number of assigned pupils per school.
Analysis at the school district level for the 2000/01 school year

This section shows how the optimization according to scenario A affects the school districts, starting with the school districts with the largest number of schools with a concentration index of over 40% in the school year 2000/01. Using the example of the Limmattal school district, the figure shows how the Zurlinden school can be reduced from the city’s highest concentration index of over 70% (scatter diagram on the left) to an index value of slightly over 40% (scatter diagram on the right). In the choropleth map below, the area swap with the school Aemtler can be traced, which leads to the catchment areas according to the optimization algorithm (see Figure 43). In fact, no traffic-related obstacles can be identified in the affected common part of the neighborhood that would speak against a boundary shift. On the other hand, the optimization does not bring any improvement for the school Hohl/Kern, which was also heavily burdened at that time. This is due to its isolated location between Sihlbahn-street (part of a western transit route back then) and the railroad tracks, on the one hand. On the other hand, there are limited exchange possibilities with the area around the school Schanzengraben (school district Zürichberg), which is clearly less burdened but also less inhabited by families. This is also true in the less restrictive scenarios B to E. Even a stronger balance with the school Limmat, which is under-proportionally burdened in comparison to its ‘neighborhood’, or with the school Sihlfeld would probably have required an increase of the maximum school route and possibly also of the maximum occupancy by more than 10 percent, supplemented with a safeguarding of the school routes along heavily used traffic axes.

Figure 46: Scatter plots and choropleth map for the concentration index according to reconstructed catchment areas and optimized catchment areas in scenario A for the school district Limmattal (2000/01).

Notes: Compare explanations on Figures 22 and 45. The thick black lines in the choropleth map mark the reconstructed catchment areas, the thin black lines the school district boundaries. The red arrows indicate which street blocks would have to be assigned to a different school according to scenario A (see Figure 43). The red labeled
schools Zurlinden, Aegerten and Hohl/Kern had the highest concentration indices citywide at that time, while the black labeled school Aemtler had the second lowest index in the school district. The school Schanzengraben belongs to the schools in the city with a clearly below-average concentration index (cf. position in the ordered legend of Figure 44). No lower school pupils could be identified in the completely white areas.

A complex area swap is proposed for the northern part of the Letzi school district, in which three schools are brought from a concentration index of around 50% to an index of below 40% (Figure 47). The effect is particularly clear for the school Kappeli, which enters into an area exchange with the schools Utogrund and Altstetterstrasse (see red arrows in the choropleth map). The school Im Herrlig exchanges with Chriesiweg, Dachsler and Altstetterstrasse, whereas the school Altstetterstrasse itself enters into an exchange with the schools Dachsler and Untermoos. Like the Hohl/Kern school before, the Grünau school, located between the highway and the river, is not able to reduce the highest concentration index in the Letzi school district.

Letzi school district (catchment areas 2000/01) / Optimization (scenario A)

Figure 47: Choropleth map and scatter plots of the concentration index according to reconstructed catchment areas and optimized catchment areas in scenario A for the Letzi school district (2000/01).

Notes: Compare remarks on figures 20 and 43. The thick black lines mark the reconstructed catchment areas, the thin black lines the school district boundaries. The red arrows indicate which street blocks would have to be assigned to a different school according to scenario A (cf. Figure 43). The red labeled schools Grünau, Kappeli, Altstetterstrasse and Im Herrlig had the highest concentration indices in the school district at that time (cf. position in legend of figure 44). No lower school pupils could be identified in the completely white areas.
The optimization potential shown for the Schwamendingen school district is even more impressive (Figure 48). Here it is striking that the reconstructed valid catchment areas in the school year 2000/01 not only reproduced the effect of residential segregation on the school composition, but they even exacerbated it (steep blue line). In particular, the concentration index of the Hirzenbach and Auhof schools turns out to be disproportionately high due to the applicable catchment areas, in comparison to their school 'neighborhood'. Conversely, the index value for the applicable catchment area of the school Mattenhof is even significantly lower than the already very low value for its school 'neighborhood'. In fact, the optimization allows for an extensive equalization of most schools (flat red line). In particular, the schools Hirzenbach and Auhof, in exchange with the schools Probstei, Mattenhof and Luchswiesen, achieve a reduction of the concentration index from almost 50% to below 40% and are thus aligned with the other schools in the school district.

The choropleth map in particular shows how boundaries in the catchment areas can reinforce the discrepancy between neighboring schools without any compelling reasons being discernible. Finally, according to the reconstruction, the catchment areas already ran across the larger traffic axes before. Especially between the disproportionately burdened school Hirzenbach and the particularly poorly mixed school Mattenhof, a clear
equalization occurs with optimized catchment area boundaries. A similar effect arises between the then also more burdened school Auhof and the then under-proportionally burdened school Luchswiesen. Although the low concentration index of the Probstei school is consistent with its immediate 'neighborhood', here too the boundary drawing at the time did little to promote mixing. With the area swaps in the optimized solution, this school also makes a significant contribution to relieving the burden on the Hirzenbach and - also indirectly via the Luchswiesen school - Auhof schools.

Finally, also in the Schwamendingen school district we identify one school whose increased concentration value remains unaffected by the optimization efforts (applies to all scenarios A to E). A look at the traffic loads in Figure 24 shows that the isolation of the Auzelg school has less to do with safety on the way to school than with its isolated location on the outskirts of the city. Thus, compared to the scenarios examined here, a stronger intermixing with the neighboring quarters would require greater flexibility with respect to school route lengths as well as a more extensive relocation of capacities. In the extreme case, we could even consider a complete relocation of pupils in the Auzelg neighborhood to the Saatlen school or today to the newly built Leutschenbach school.

In other less strained school districts, it is often individual schools with a higher burden that improve their position by swapping areas within their school district (Figure 49): in the Uto school district, the Aegerten school lowers its share from 70% to a good 50%, in the Waidberg school district, the index of the Nordstrasse school drops to almost 40%, and in the Glattal school district, the Gubel and Kolbenacker schools even drop from 40% to the citywide average of around 30%. Even within the Zurichberg school district, a balance can be seen between the schools, even if these already had concentration indices of around 20% or less in the initial situation.

The fact that balancing within the school districts is more pronounced than across the entire city is largely explained by the restrictive conditions applied in the simulations here. Although the school district borders were not specified in the optimization, we find hardly any indications for the need of district border transgressions. A look at Figure 43 with the city-wide catchment area map shows for all optimization scenarios that boundary transgressions occur only selectively. They happen mostly in areas where we see border transgressions in the reconstructed valid catchment areas already, partly persisting till the present day.

A look back at the citywide choropleth map (Figure 22, chapter data and methods) explains why small-scale optimization is hardly possible along the school district borders. In several cases, the border areas are only sparsely populated or not populated at all due to their natural conditions and thus make mixing difficult: the river basin between Limmattal and Waidberg as well as between Letzi and Waidberg, the inner city between Limmattal and Zurichberg, and finally forest between Schwamendingen and Zurichberg as well as between Waidberg and Glattal. Moreover, the inhabited border areas are characterized by similarly low or similarly high concentration indices: The former case applies between Waidberg and Zurichberg, the latter between Schwamendingen and Affoltern, Limmattal and Letzi, and Limmattal and Uto. Occasionally, however, differences can be found even in these cases, which can be leveled out by adjusting the catchment areas across the school districts: for example, between the schools Im Gut (Limmattal) and Küngenmatt (Uto), or between Utogrund (Letzi) and Hardau (Limmattal; cf. optimized catchment areas in Figure 43). For this reason alone, greater flexibility in defining the catchment areas across the school districts appears as highly desirable.
Figure 49: Scatter plots of the concentration index according to reconstructed catchment areas and optimized catchment areas in scenario A for the other school districts of the city of Zurich (2000/01).
An even greater flexibilization of school district boundaries would be necessary if one wanted to level out the conspicuous differences in concentration indices on both sides of the Limmat river (see also Figure 23, chapter data and methods). Indeed, until the summer of 2019, the lightly burdened school Am Wasser (Waidberg school district, north of the Limmat) also served large parts of the former industrial district in Kreis 5 (Limmattal school district, south of the Limmat), leading at least initially to a certain degree of mixing. The short distance between the schools Kornhaus (south, Limmattal school district) and Letten (north) would favor a stronger area swap with appropriate school route safety measures. The school Grünau (south, Letzi school district), in turn, would profit from an area swap with the more distant schools Pünten and Am Wasser (both north). Here it becomes clear how strongly the exchange possibilities depend on the school locations. Understandably, these are in the middle of historically grown neighborhoods and - due to the general allocation within the school districts - only rarely near the school district borders. In this respect, future school space planning should explore whether school locations in border areas would be feasible for integrating differently composed neighborhoods more strongly. Similarly, the planning literature (Talen 2018; Fincher and Iveson 2008) recommends placing common meeting areas (shopping facilities, libraries, public squares, meeting centers) precisely between such neighborhoods in order to ensure a certain degree of mixing, at least in terms of shopping and recreation. This should also apply to schools as potentially integrating institutions. Consequently, a strategic adjustment of the school district boundaries first requires a flexibilization regarding school space planning and catchment areas, which would not need to follow school district boundaries.

**Preliminary analyses for the 2019/20 school year**

In a similar way to the 2000/01 school year, we calculated concentration indices for school catchment areas and school 'neighborhoods' for the 2019/20 school year, using the 2010 to 2015 pooled structural surveys. Since these are random samples, the focus was not on the foreign language proficiency and educational background of first- to third-graders themselves, but on foreign language and educational level of the general resident population. This is likely to significantly underestimate the actual proportion of such pupils, especially where the concentration values would be highest (e.g., bias due to native retirees, childless persons with a teaching degree). In addition, the data basis hides more recent developments over the last four years. The values shown in Figure 50 for the school year 2019/20 thus correspond to an estimate and they are also not directly comparable with the indices for the school year 2000/01 (Figure 22). Nevertheless, compared to the situation at that time, a relative shift of the residential areas with the highest concentration values can be observed. In particular, the upgrading processes in the Longstreet neighborhood as well as along the traffic-calmed former western transit route in the Limmattal (and Uto) school district have caused significant drops in concentration indices for several schools. This shifts the focus to the still burdened neighborhoods further northwest between Hard and the western city border as well as to individual school neighborhoods in Schwamendingen. This shift is also in line with the convergence of the transfer rates to the secondary level between the Limmat and Letzi school districts described above, while in relative terms the highest proportion of transfers to the less demanding secondary school B is currently to be found in the Schwamendingen school district (see chapter unequal access to education).

This shift is more clearly visible in our internal cartographic evaluation (not shown) of the school 'neighborhoods' according to the updated school building stock - analogous to Figure 23. It becomes visible that many of these more burdened school 'neighborhoods' are adjacent to areas with a significantly lower concentration index towards the south or towards the north, which means that in these cases we can generally assume a high mixing potential.
For the assessment of the school composition, we again use the school catchment areas, whereby for the current school year we can rely on the spatial data provided by the school authority. The data reflect the provisional catchment areas for school year 2019/20, including the catchment areas for new schools opening by then. The composition of the schools is estimated based on the composition of the resident population that resided within these catchment areas and was covered by the structural survey in the years 2010 to 2015. An own cartographic analysis (not reported) reveals that the observed shift in school ‘neighborhoods’ with higher concentration indices also affects the relative concentration values of schools. At the same time, the comparison to school concentration values in the 2000/01 school year shows that the relative burden among schools has also changed within these areas. Consequently, optimization today would have to partially compensate in the opposite direction. More important for all these schools, however, is the balance with the neighboring schools to the south, which then as now can contribute to a two-way mix with low concentration values. In this respect, little has changed, especially in the school districts Letzi and Schwamendingen.

The fact that school segregation reflects residential segregation in a city-wide view is shown in Figure 51, in which, as in 2000/01, the concentration values for all schools are shown - both in relation to their hypothetical ‘neighborhood’ (horizontal axis), as well as in relation to their actual composition (vertical axis). Thus, residential segregation is most likely reproduced almost one-to-one in school assignment across catchment areas even today. The question of whether the city of Zurich’s school authorities are now leaving mixing potential unused, as they did in the 2000/01 school year, cannot be answered definitively on the basis of this analysis. This would require an optimization analysis based on internal school data on pupils. In principle, however, no reasons are apparent why a less pronounced balancing should be possible in the 2019/20 school year than in the 2000/01 school year, particularly at the school district level.
Module 2: Room for maneuver for greater mixing

Figure 51: Scatter plot of the relationship between residential and school segregation in the city of Zurich (2019/20), based on structural survey data 2010-2015.

Note: The figure shows a weighted scatter plot of the relationship between a) school-specific concentration indices (see chapter data and methods) according to catchment areas 2019/20 (‘catchment area’), based on the catchment areas from the Zurich City School Board, and b) the corresponding concentration indices that would result from counterfactual catchment areas (‘neighborhoods’) if each person were simply assigned to the closest school. In contrast to Figure 27, the concentration index is not based on the assumed lower school pupils, but on the resident population between 25 and 65 years of age and their first language and educational level according to the 2010-2015 pooled structural survey (sample). Each bubble represents a school (possibly several schools with a common catchment area). The OLS regression line and the 45° line are shown for comparison.

In contrast to 2000/01, this time we cannot identify any school district where the defined catchment areas would reinforce the effect of residential segregation. However, individual schools continue to be disproportionately burdened, and these cases can be explained by geographic circumstances (scatter diagrams for individual school districts not reported).

Since the 2000/01 school year, several new school sites have been opened, reconfiguring school ‘neighborhoods’ (Voronoi diagrams when allocated by air distance) and school catchment areas locally. Depending on the schools’ location and the design of its catchment area, it is conceivable that these new schools could either encourage, or discourage, greater mixing. If the new school sites allow differently composed neighborhoods to attend school together, the former occurs. But if they lead to a homogeneously composed catchment area, at best they contribute to the continued replication of residential segregation. In the worst case, however, school segregation is even reinforced, as N more diverse school ”neighborhoods” are now replaced by N+1 more homogeneous school ”neighborhoods”, thus making it more difficult to achieve at least potentially more mixed catchment areas.
Based on the choropleth map in Figure 50, as well as internal cartographic evaluations of school ‘neighborhoods’, an initial assessment can be made as to whether new school building locations have led to increased mixing potential. As mentioned above, the interpretation must consider that the data basis refers to the resident population (instead of the student body) and that socio-demographic developments due to new buildings have not yet been considered. The location of the Leutschenbach school (Schwamendingen school district), for example, with the simultaneous existence of the Auzelg school, makes it difficult to achieve a greater mix in this city area. The recently opened Pfingstweid school (Limmattal school district) in the newly built Zurich West district will also hardly contribute to mixing due to the railroad tracks to the south and the distance to the Grünau neighborhood. And even with the neighboring Schütze school, which opened the same day, the leveling possibilities remain minimal due to the railroad tracks and due to the strongly upgraded existing neighborhoods further east.

Similar considerations are likely to apply to the numerous ongoing new construction projects with primary schools (cp. Stadt Zürich 2019b), although here it is all the more important to point out the lack of data on newly developing settlement areas. At least based on the composition 2010 to 2015 (Figure 50), we must expect that the school sites are either located in homogeneous large areas, or that the newly created school ‘neighborhood’ is too small and unable to capture the large-scale diversity. The latter case is illustrated by the projected school Allmend in the Uto school district. While this school is intended as “school space oriented towards Leimbach”, its chosen location at the northern end of the Green City is likely to serve mainly the newer developments being built. After all, a certain mix was considered in the planning of the Green City (one third of the apartments were reserved for non-profit housing developers). Moreover, data for 2010 to 2015 show that the greater Leimbach area was characterized by less social and ethnic segregation than other areas of the city.

In general, these assessments of the new school buildings are not intended to question the demonstrable need for school space at the selected locations. We merely wish to point out that the new schools have so far not provided any expanded opportunities for greater mixing.

**Basel**

**Optimization of catchment areas in the 2000/01 school year**

As for Zurich, we also compare the reconstructed catchment areas for Basel for the 2000/01 school year with five scenarios for their optimization in the sense of greater mixing (Figure 52). For Basel, too, a considerable citywide leveling effect can already be shown with scenario A of the citywide analysis (flatter regression line in Figure 53). Schools with particularly high or particularly low concentration values can be brought closer to the citywide mean. An expansion of the scope in terms of maximum distance and/or maximum school capacities brings only minimal additional leveling (scenarios B-D). Only the possibility of allowing catchment areas to interpenetrate each other (scenario E) creates a significantly stronger equalization in the school year 2000/01, although the schools with the citywide highest concentration values are hardly affected by this equalization. Instead, the stronger mixing affects schools with concentration values in the upper middle range as well as schools at the lower end of this value scale.
Figure 52: Maps of the reconstructed and optimized catchment areas according to different scenarios for the city of Basel (2000/01).

Note: Compare comments on Figure 43.
(I) Catchment areas 2000/01

(A) Optimization (max.dist. +5%, max.cap. +/-5%)

(B) Optimization (max.dist. +10%, max.cap. +/-5%)

(C) Optimization (max.dist. +5%, max.cap. +/-10%)

(D) Optimization (max.dist. +10%, max.cap. +/-10%)

(E) Scenario D with interpenetrating catchment areas

Figure 53: Scatter plots of the relationship between residential and school segregation with comparison to different optimization scenarios in the city of Basel (2000/01).

Note: Compare explanations on Figure 44.
Analysis at the school district level for the 2000/01 school year

For Basel, too, we examine the optimization potential at the level of the school districts in more detail. Unlike in Zurich, however, a school district boundary can be identified in Basel that cuts through a densely populated residential neighborhood - namely where school district 1 reaches across the Rhine into the Kleinbasel side. We have combined the corresponding schools of school district 1 and school district 2 into schools of Kleinbasel and shown the optimization potential according to scenario A (Figure 54).

The analysis reveals that the Horburg-Schlössli school, which had the citywide highest concentration value in 2000/01, can be relieved by the Bläsi school by 7 percentage points, although the Bläsi school can also be slightly unburdened compared to the initial situation through area swaps with the Theobald and Theodor schools. The latter school, however, is in school district 2. Apart from this, school Ackermätteli can be relieved by 8 percentage points within school district 2 through area swaps with school Kleinhüningen. Overall, the scatter plot shows that the mixing on the Kleinbasel side is limited to these areas closer to the center, while the schools Schoren and Hirzbrunnen remain uninvolved in the mixing. In fact, the regression line for the more densely populated area...
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(excluding Schoren and Hirzbrunnen) would be much flatter. To further relieve this urban area and to involve the schools Schoren and Hirzbrunnen in the mixing (via the school Vogelsang), longer school routes would be necessary, which would also have to go significantly beyond the additional 10 percent in scenario B (cf. three data points on the outer right in Figure 53).

School district 1, Grossbasel part (catchment areas 2000/01) / Optimization (scenario A)

School district 1, Grossbasel part (catchment areas 2000/01) / optimization (scenario E)

Note: Compare comments on Figure 46.

Figure 55: Scatter plots for scenarios A and E and choropleth map for the concentration index according to reconstructed catchment areas and optimized catchment areas in scenario A for the Grossbasel part of school district 1 (2000/01).
School district 1 (catchment areas 2000/01) / Optimization (scenario A)

School district 2 (catchment areas 2000/01) / Optimization (scenario A)

School district 3 (catchment areas 2000/01) / Optimization (scenario A)

School district 3 (catchment areas 2000/01) / Optimization (scenario E)

Figure 56: Scatter plots of the concentration index according to reconstructed catchment areas and optimized catchment areas in scenario A and scenario E, respectively, for all school districts of the city of Basel (2000/01).
Although the schools in the Grossbasel part of school district 1 show generally lower concentration values, under scenario A the most heavily burdened school St. Johann (48 percent) can be brought closer to the 40 percent threshold (Figure 55, see top panel on the right). Slight relief can also be achieved for Wasgenring, the second most heavily burdened school. While both schools swap territories with the school Isaak Iselin, which is located in between, all three schools can achieve a clear balance with the less mixed schools Peters and Gotthelf.

What relaxing the requirement of contiguous catchment areas (scenario E) can bring is clearly visible in the Grossbasel part of school district 1 (Figure 55, second top panel on the right). By allowing a penetration of the catchment areas as well as a larger leeway with respect to school route length and school capacities, the composition of the schools can be leveled out almost completely. In addition to the area swaps outlined above, the catchment area of the St. Johann school (where school routes are already long in the status quo) is expanded in the direction of the previous areas of the Peters and Gotthelf schools (cf. catchment area colored in blue in Figure 52).

For the sake of completeness, we also show the scatter diagrams separately according to the currently valid school district boundaries (Figure 56). For school district 1, the entire range of concentration values between the Grossbasel and Kleinbasel sides becomes visible, as does the leveling effect, which, as explained above, sets in separately on the Grossbasel and Kleinbasel sides. In the scatter diagram for school district 2, a large part of the leveling is hidden, since the three Kleinbasel schools of school district 1 are not accounted for. The mixing of the Ackermätteli school has little weight in view of the Schoren and Hirzbrunnen schools, which remain involved in the mixing. On the other hand, the new scatter diagram for school district 3 shows the strongest balancing effect, whereby the schools Margrethen and Thierstein, which were more heavily burdened at the time, can be relieved indirectly or directly via the hitherto less mixed school Burderholz. Like the previous scenario for the Grossbasel part of school district 1, school district 3 also shows a large mixing potential if the requirement of contiguous catchment areas is relaxed (scenario E). The two scenarios for school district 3 have in common that the school Neubad Nord cannot be involved in the mixing.

**Preliminary analyses for the 2019/20 school year**

For Basel and the cities studied further, we also draw on the sample data from the pooled structural surveys for a preliminary analysis. In contrast to the pilot study, however, we account for the extended period from 2010 to 2018. Despite a different population (residential population instead of pupils), relative shifts in terms of social stress in the neighborhoods can also be observed in the updated choropleth map for Basel (Figure 57). These shifts become more clearly visible when the concentration index is aggregated by 'school neighborhoods' as well as by reconstructed school catchment areas of 2019/20 (not reported). In the section of school district 1 on the Kleinbasel side, we detect continued elevated concentration values, but relative to this, the schools to the north of this estimated based on residential population - have more heavily burdened catchment areas. Equally, the area southeast of this section also appears to be less privileged in relative terms. At the same time, we note neighborhoods and schools in relative proximity to the east of the section, which appear to be relatively less mixed due to the low concentration values.

A relative shift of social stress is even more apparent on the less burdened Grossbasel side, away from the St. Johann school towards the newly built elementary school in the north of the school, but also towards the schools already existing in 2000 to the west of the school. In school district 3, on the other hand, the relative burden of the Margarethen and Thierstein schools seems to have dissipated due to changes in the residential population, and all school catchment areas show low concentration values in terms of residential population and thus little social and ethnic mixing.
The Basel transfer rates shown at the beginning of the study also reflect the shifts described, whereby the fine-grained breakdown of the data makes it particularly visible, how educational pathways vary by place of residence even within the school districts, especially on the Kleinbasel side (see chapter unequal access to education).

If the concentration values at the level of the neighborhoods and the school catchment areas are currently put into relation, a slight flattening can be seen in comparison with the situation in 2000. This flattening would indicate a balancing effect of the current catchment areas, but it also shows that this flattening is mainly due to two schools composed disproportionately to the neighborhood. Interestingly, these are two neighboring Kleinbasel schools, with the catchment area of one school showing a significantly under-proportional concentration value when measured against its neighborhood, while the catchment area of the other school shows a significantly over-proportional concentration value when measured against its neighborhood. If we disregard these two schools, it becomes clear that the concentration values of the catchment areas largely reproduce residential segregation between neighborhoods.

Concentration values in Basel can also be explained in part by the schools’ peripheral locations, for example north of the above-mentioned section on the Kleinbasel side, or north of the St. Johann school. It should be noted, however, that the schools north of the St. Johann school are relatively newly built schools. Thus, the peripheral locational decision for these schools did not serve the purpose of mixing. In addition to such peripheral locations, there are also catchment areas which today show increased concentration values, but which are in the immediate vicinity of school catchment areas with extremely low concentration values. A detailed analysis based on current individual data could thus also clarify the question of optimization potential for Basel, if necessary supplemented with analyses of necessary measures in school route safety or in future school space planning.
Bern

Optimization of catchment areas in the 2000/01 school year

For the city of Bern, too, the reconstructed catchment areas for the school year 2000/01 are compared below with the five scenarios for optimizing these same catchment areas (Figure 59). In contrast to Zurich and Basel, scenario A for Bern shows only a weak city-wide mixing potential (weak flattening of the regression line in Figure 60), which is probably due to the more fragmented settlement area of the city of Bern. Nevertheless, this slight leveling comes about through the substantial relief of individual schools with particularly high concentration values. While a relaxation of the specifications regarding the length of school routes (scenario B) hardly contributes to a stronger mixing, the city-wide leveling can be further increased with certain shifts in school capacities (scenario C), especially in connection with slightly longer school routes (scenario D). The additional allowance of a mutual interpenetration of catchment areas (scenario E), however, hardly seems to be able to contribute to a stronger leveling - unlike in Basel.
(0) Catchment areas 2000/01

(A) Optimization (max.dist. +5%, max.cap. +/-5%)

(B) Optimization (max.dist. +10%, max.cap. +/-5%)

(C) Optimization (max.dist. +5%, max.cap. +/-10%)

(D) Optimization (max.dist. +10%, max.cap. +/-10%)

(E) Scenario D with interpenetrating catchment areas

Figure 59: Maps of the reconstructed and optimized Catchment areas according to different scenarios for the city of Bern (2000/01).

Note: Compare comments on Figure 43.
Figure 60: Scatter plots of the relationship between residential and school segregation with comparison to different optimization scenarios in the city of Bern (2000/01).

Note: Compare comments on Figure 44.
Analysis at the school district level for the 2000/01 school year

In Bern, too, the leveling effect is better revealed by the analysis on the individual school districts. Like the Schwamendingen school district in Zurich, the Bethlehem school district in the school year 2000/01 shows an exacerbating effect of the school catchment areas by reinforcing existing residential segregation in terms of school compositions (regression line steeper than 45° line). This can be attributed to the disproportionately low concentration value of the Bethlehem school compared to the respective neighborhood, while at the same time the concentration value in the Schwabgut school is disproportionately high. Already in scenario A, the Schwabgut school, then the school with the highest percentage (59 percent) of pupils from foreign-language and educationally disadvantaged families in the city of Berne, could be relieved by 10 percentage points by the Tscharnerguet, Stöckacker and Höhe schools (Figure 61). The Höhe school, located in the neighboring Bümpfliz school district, can maintain its concentration value at 40 percent by taking over a street block from the Statthalter school in the same school district. The school with the second highest concentration value in the city back then, the Tscharnergut school - again in the Bethlehem school district - can reduce its value by 8 percentage points by entering into an area swap with the Gäbelbach school and the Bethlehemacker school, which - measured against its immediate surroundings - has so far been significantly under-proportionally burdened.

Regarding the possible leveling within the school district Bümpliz, this turns out to be modest, which is not least due to the lack of exchange possibilities with the far away and less mixed school Oberbottigen. Nevertheless, it can be shown that the concentration values of the schools in the school district Bümpliz remain in an acceptable value range of below 40 or even below 30 percent, despite contributing to the relief in the neighboring school district Bethlehem.

In comparison, little can be done for the Bernese school Steigerhubel in the Mattenhof-Weissenbühl school district, which was the third most heavily burdened school in 2000/01 (Figure 62). This is true not only under the restrictive scenario A, but also with relaxed boundary conditions according to scenarios B to E (cf. corresponding data point in Figure 60). This circumstance can be explained by the fact that the Steigerhubel school occupies a peripheral position within the school district, while the mutually accessible border parcels do not allow for balancing between the schools due to their composition. The compact catchment area of the Stöckacker school in the neighboring Bethlehem school district also remains inaccessible. However, a stronger mix can be achieved in this school district, namely for the Brunnmatt and Pestalozzi schools, with the Sulgenbach school also participating in the leveling between the two schools (Figure 62).

In the other school districts, under scenario A we observe no significant improvements for any of the schools in terms of their mix (Figure 63).
Bethlehem school district (catchment areas 2000/01) / optimization (scenario A)

School district Bümpliz (catchment areas 2000/01) / Optimization (scenario A)

Figure 61: Scatter plots and choropleth map for the concentration index according to reconstructed catchment areas and optimized catchment areas in scenario A for the school districts Bethlehem and Bümpliz (2000/01). Borders separating the school districts is marked with a red dotted line.

Note: Compare comments on Figure 46.
Mattenhof-Weissenbühl school district (catchment areas 2000/01) / optimization (scenario A)

Figure 62: Scatter plots and choropleth map for the concentration index according to reconstructed catchment areas and optimized catchment areas in scenario A for school district Mattenhof-Weissenbühl (2000/01). Borders separating the school districts is marked with a red dotted line.

Note: Compare comments on Figure 46.

Kirchenfeld-Schlosshalde school district (catchment areas 2000/01) / optimization (scenario A)
Breitenrain-Lorraine school district (catchment areas 2000/01) / optimization (scenario A)

Länggasse-Felsenau school district (catchment areas 2000/01) / optimization (scenario A)

Figure 63: Scatter plots of the concentration index according to reconstructed catchment areas and optimized catchment areas in scenario A for the other school districts of the city of Bern (2000/01).

Preliminary analyses for the 2019/20 school year

When looking at the current concentration values for the resident population in the detailed choropleth map (Figure 64), but more clearly in the internal evaluations for the school neighborhoods and in the school catchment areas (not reported), a relative accentuation of the social burden in isolated schools in the western two school districts of Bethlehem and Bümpliz can be observed for Bern. Thereby, at least four schools can also be identified between these schools, which today have relatively low concentration values. In terms of transfer rates by school district (cf. chapter unequal access to education), this accentuation became particularly visible in the Bethlehem school district, where, contrary to the developments in the other school districts, the proportion of transfers to the Realschule increased compared to 2000.

Increased concentration values can also be found in the Mattenhof-Weissenbühl school district south of the city center and somewhat less pronounced in the Breitenrein-Lorraine school district in the northeast of the city. In all these cases, the schools are disproportionately burdened compared to their school neighborhood, i.e., the data points are above the 45° line in Figure 65. However, there are neighboring schools to all these schools that show particularly low concentration values compared to their surroundings, i.e., they are below the same line in Figure 65. In principle, this indicates existing mixing potential, although a definitive assessment would require modeling of optimized catchment areas based on current individual data. However, it can be assumed that, as in the 2000/01 school year, mixing will be more successful in the more densely populated contiguous areas, while in the outlying areas, additional measures will be necessary: ensuring safety on the way to school, school space planning, urban planning, and housing promotion.
Figure 64: Choropleth map on the concentration index for the city of Bern (2010-2018) and school locations in the school year 2019/20.

Comments: In contrast to Figure 31 (left), the concentration index is not based on lower school pupils, but on the resident population between 25 and 65 years of age and their first language and educational level according to the 2010-2018 pooled structural survey (sample).

Figure 65: Scatter plot of the relationship between residential and school segregation in the city of Bern (2010-2018).
Comments: In contrast to Figure 31 (left), the concentration index is not based on lower school pupils, but on the resident population between 25 and 65 years of age and their first language and educational level according to the 2010-2018 pooled structural survey (sample). For this purpose, street blocks per school were weighted with the respective number of 1st-3rd graders and basic level pupils of the school residing there (no actual reconstruction of the catchment areas, see remark in the section data availability in the appendix).

Geneva

Optimization of catchment areas in the 2000/01 school year

(0) Catchment areas 2000/01

(A) Optimization (max.dist. +5%, max.cap. +/-5%)

(B) Optimization (max.dist. +10%, max.cap. +/-5%)

(C) Optimization (max.dist. +5%, max.cap. +/-10%)

(D) Optimization (max.dist. +10%, max.cap. +/-10%)

(E) Scenario D with interpenetrating catchment areas

Figure 66: Maps of the reconstructed and optimized Catchment areas according to different scenarios for the city of Geneva (2000/01).

Note: Compare explanations on Figure 43.
Comparing the reconstructed catchment areas for the school year 2000/01 in the city of Geneva with the optimization scenarios A to E (Figure 66) shows that the already slightly equalizing initial situation in Geneva can be leveled even more (Figure 67). This is the case already with the most restrictive scenario A with existing maximum school route length and school capacities. A relatively pronounced additional equalization can be identified for schools in neighborhoods with low concentration values as well as for schools in neighborhoods with high concentration values (data points left and right in the scatter plot). Unlike in Basel and Bern, no additional mixing potential can be identified in the less restrictive scenarios B to E.
Analysis at the school district level for the 2000/01 school year

Firstly, we must note that for the city of Geneva in 2000/01, the school with the highest proportion of pupils from disadvantaged social and linguistic backgrounds, the Aliborges school, has a peripheral location (Figure 68). This makes mixing with neighboring schools very difficult. The parcels with the highest concentrations are turned away from the neighboring schools, making a relieving area swap under scenario A impossible due to the implied school route distances. However, even an expansion of the leeway in terms of school route length or school capacity to 10 percent is not sufficient in this case (scenarios B-D, cf. outermost data point on the right in Figure 67). Significantly longer school routes or a strong expansion or complete dissolution of school capacity would be necessary for a mix.

The mixing also turns out to be rather modest for the third most burdened school in Geneva, Plantaporrets (Figure 68). Smaller area swaps are possible with the schools Cite Jonction and Mail, which, however, already have concentration values of around 40 percent according to the valid catchment areas of 2000/01. It is noticeable that an area swap with the schools of the neighboring school districts Saint-Jean Charmilles and Grottes Saint-Gervais does not appear possible in the case of the Plantaporrets school under scenario A. Greater congestion relief for the Plantaporrets school would require slightly longer maximum school commute lengths (scenario C, see second data point from the right in Figure 67). Instead, in this school district, the leveling in scenario A comes from the fact that the school with the second highest concentration value at the time, Dumas School, can be relieved by 14 percentage points through area swaps with Michell-du-Crest School as well as Roseraie (in the neighboring Plainpalais Jonction school district). In addition, the schools Mail and Hugo-de-Sengel, which are more heavily burdened, can be leveled out by swapping territories with the school Carl-Vogt. The Saint-Antoine school in the neighboring school district also participates in the relief of these two schools, whereby the relief in the case of the Hugo-de-Sengel school is also made possible indirectly via the Michell-du-Crest school.

The scatter diagrams for the other school districts whose schools do not reach the 40 percent mark are shown separately (Figure 69). The leveling is most clearly visible in the case of the Eaux-Vives Cité school district. Not only does the Saint-Antoine school contribute to the above-mentioned relief of the Mail and Hugo-de-Sengel schools, but there is also a balancing exchange of territories between the Eaux-Vives and XXXI-Decembre schools on the one hand and the Montchoisy school on the other. Also involved is the school Contamines in the neighboring school district Plainpalais Jonction - which also causes a flattening of the regression line in the scatter diagram to the latter school district. The Roseraie school there, which, as explained above, participates in the relief of the Dumas school in the Champel school district, can, on the other hand, only be compensated for this to a limited extent within the school district. It is also worth mentioning the leveling in the school district of Saint-Jean Charmilles, where equalizing exchanges of territories take place between the schools of Charmilles, Geisendorf and Lienard on the one hand, and the schools of Devin-du-Village and Veusseux on the other.
Figure 68: Scatter plots and choropleth map for the concentration index according to reconstructed catchment areas and optimized catchment areas in scenario A for the Champel school district (2000/01). Borders separating the school districts is marked with a red dotted line.

Note: Compare comments on Figure 46.
Eaux-Vives Cité school district (catchment areas 2000/01) / Optimization (scenario A)

Grottes Saint-Gervais school district (catchment areas 2000/01) / Optimization (scenario A)

Pâquis Sécheron school district (catchment areas 2000/01) / Optimization (scenario A)

School district Plainpalais Jonction (catchment areas 2000/01) / Optimization (scenario A)
Saint-Jean Charmilles school district (catchment areas 2000/01) / Optimization (scenario A)

School district Servette Petit-Saconnex (catchment areas 2000/01) / Optimization (scenario A)

Figure 69: Scatter plots of the concentration index according to reconstructed catchment areas and optimized catchment areas in scenario A for the other school districts of the city of Geneva (2000/01).

Preliminary analyses for the 2019/20 school year

For Geneva, too, the choropleth map of the residential population (Figure 70) shows certain shifts in the concentration values, which can be seen more clearly in our internal evaluations by school neighborhoods (not reported). In particular, the upgrading of the residential neighborhoods in the previously heavily burdened Grottes Saint-Gervais school district in the center and a certain upgrading in the Champel school district south of it are visible. In this respect, high concentration values are still most visible today in the isolated school district Acacias Bâtie as well as single neighborhoods in the school district Saint-Jean Charmilles.

In contrast to the cities discussed so far, the current effect of catchment areas on the relationship between residential and school segregation cannot be studied in more detail in Geneva. Because access to cantonal education statistics was not permitted, it was not possible to reconstruct current school catchment areas to calculate concentration values based on structural survey data for schools as well. While the publicly available data on the nationality and socio-professional background (cf. Table 2 in the appendix) of the pupils allowed the calculation of an improvised concentration index on the composition of the schools, the divergence in the indicators used prevented us from relating it directly to concentration values for the school ‘neighborhoods’.

Instead, we use the current data on the student body to show the variance that the individual school districts have in terms of the composition of their schools (Figure 71). Here, the schools of the same school district are ordered on the horizontal axis according to the overall composition of the school district. The range of values for the schools shifts upward as the concentration index for the entire school district increases, but school districts 1, 3, and 8 - the three school districts in the southeast - show a wide dispersion. In addition to the school in the Acacias Bâtie school district located southwest of the city (not reported), the highest concentration values for isolated schools in the school districts Champel (8), Pâquis Sécheron (2), and Plainpalais Jonction (1) are absent, followed
by generally slightly higher concentration values in the school districts Saint-Jean Charmilles (6) and Grottes Saint-Gervais (4). In particular, the high concentration values for individual schools in school districts 2 and 1 had not been expected from the analyses on school neighborhoods, although in these particular cases conditions regarding school routes could possibly be decisive.

Overall, the analysis possible here on the basis of limited data suggests a need for mixing in particular between the Acacias Bâtie school district (5) and the schools in Champel (8), which lies to the north of it. For the very differently composed schools in the Champel school district (8), and for the more evenly burdened schools in the Saint-Jean Charmilles school district (6), a stronger mixing potential would have to be examined within the districts but also in the border area with the school districts Servette Petit-Saconnex (7) and Eaux-Vives Cité (3). In addition to matters of urban planning and housing policies in the southern school districts of the city, it is precisely in these latter border areas that the question of school space planning arises, which would allow a greater mixing across the school district border in the first place. Between Champel (8) and Eaux-Vives Cité (3), new schools in the border area could greatly increase the possibilities for mixing.
Lausanne

Optimization of catchment areas in the 2000/01 school year

For the city of Lausanne, the comparison of the reconstructed catchment areas in the school year 2000/01 with the different optimization scenarios (Figure 72) shows only a weak optimization potential. The potential increases only minimally even with extended leeway with respect to maximum school route lengths and school capacities or even with respect to the interpenetration of the catchment areas (Figure 73). Nevertheless, some relief can be achieved at least for the schools with the highest concentration values on the right-hand edge, while numerous schools in the left-hand half of the scatter diagram are brought closer to the composition of their neighborhoods in terms of their composition (45° line).
Figure 72: Maps of the reconstructed and optimized Catchment areas according to different scenarios for the city of Lausanne (2000/01).

Note: See comments on Figure 43. In contrast to the other cities, Lausanne’s catchment areas were reconstructed by considering pupils in the first four years of lower school (HarmoS counting method).
Module 2: Room for maneuver for greater mixing

(0) Catchment areas 2000/01

(A) Optimization (max. dist. +5%, max. cap. +/-5%)

(B) Optimization (max. dist. +10%, max. cap. +/-5%)

(C) Optimization (max. dist. +5%, max. cap. +/-10%)

(D) Optimization (max. dist. +10%, max. cap. +/-10%)

(E) Scenario D with interpenetrating catchment areas

Figure 73: Scatter plots of the relationship between residential and school segregation with comparison to different optimization scenarios in the city of Lausanne (2000/01).

Note: See comments on Figure 44. In contrast to the other cities, the concentration values in Lausanne were calculated for pupils in the first four years of school (Harmonization counting method).
Analysis at the school district level for the 2000/01 school year

As in Basel, Bern and Geneva, Lausanne also shows potential for mixing not only within the individual school districts, but also across school district boundaries. This is most clearly visible in the example of the Beaulieu school district, whose Pontais school is indirectly relieved by area swaps with the Bergieres school in the Pierrefleur school district (Figure 74). A certain relief is also achieved for the school Barre, whereby this is achieved through area swaps with two schools in two other school districts (Mon Repos and La Sallaz in the respective school districts of the same name). The fact that the school Pontaise is not relieved even more by the hardly mixed school Rouvraie in the school district Entre-Bois has to do with the fact that the school Rouvraie is separated by a forest, since school routes through the forest are also avoided in the data-based procedure. In the same figure, the remote school Blecherette remains unchanged with its increased concentration value. The residential areas around the Pont-de-Sauges school remain inaccessible under scenario A, as does the area near the Entre-Bois school in the neighboring school district. This also applies to scenarios B to D (cf. small data point in Figure 73).

Another example is the Prélaz school district with the most burdened school of Lausanne, the Provence school (Figure 75). Like the previous example, the school is relieved by the school district's own school Malley. The Malley school, on the other hand, unburdens itself through area swaps with the Montoie school in the neighboring Floréal school district. The Montoie school, in turn, exchanges territories with the Montriond and Floreal schools.
In the Floréal school district, again one school in a peripheral location proves not to be intermixable - the Bourdonnette school - at least not under the specifications of scenarios A to D (cf. second data point from the right in Figure 73). Finally, the school Tivoli is conspicuous, which shows a strongly under-proportional concentration value compared to the immediate surroundings. This is due to the somewhat isolated location of the school.

The school districts summarized in the examples above are also shown separately in the following scatter diagrams in Figure 76. For the other school districts, the leveling effect is particularly evident in the separate diagrams for the districts la Sallaz and Couteau-Fleuri, where the concentration values are already less than 30 percent in the initial situation.
Beaulieu school district (catchment areas 2000/01) / Optimization (scenario A)

Entre-Bois school district (catchment areas 2000/01) / Optimization (scenario A)

Floréal school district (catchment areas 2000/01) / Optimization (scenario A)

Mon-Repos school district (catchment areas 2000/01) / Optimization (scenario A)
Module 2: Room for maneuver for greater mixing

Prélaz school district (catchment areas 2000/01) / Optimization (scenario A)

La Sallaz school district (catchment areas 2000/01) / Optimization (scenario A)

Coteau-Fleuri school district (catchment areas 2000/01) / Optimization (scenario A)

Pierrefleur school district (catchment areas 2000/01) / Optimization (scenario A)

Figure 76: Scatter plots of the concentration index according to reconstructed catchment areas and optimized catchment areas in scenario A for the other school districts of the city of Lausanne (2000/01).
Preliminary analyses for the 2019/20 school year

What is less evident in the choropleth map on the current concentration index in the residential population (Figure 77) is revealed in internal aggregations of concentration values by school neighborhoods and school catchment areas (not reported): while the schools in the Prélaz school district continue to show high pressures, the relatively low concentration values in the Beaulieu school district point to upgrading processes, which is also consistent with the observation regarding transfer rates to secondary education as well as on the changing socioeconomic composition of the resident population in the area (see chapter unequal access to education). On the other hand, an increased polarization with respect to the neighborhood concentrations can be observed in the school district Entre-Bois located to the north as well as in the school districts Floréal and Couteau-Fleuri in the southwest and east of the city. Based on the reconstructed school catchment areas, this may lead to individual schools with concentrations comparable to those in the school district Prélaz, especially in Entre-Bois and in Couteau-Fleuri. It is precisely this polarization of the Entre-Bois and Couteau-Fleuri school districts that is also reflected in the reported transfer rates, according to which the proportions of both transfers to the progymnasium and transfers to the lower_requirement secondary school (level 1) have increased in the secondary school districts in question, and the medium_requirement level (level 2) has decreased.

Figure 77: Choropleth map on the concentration index for the city of Lausanne (2010-2018) and school locations in the 2019/20 school year.

Comments: In contrast to Figure 37 (left), the concentration index is not based on lower school pupils, but on the resident population between 25 and 65 years of age and their first language and educational level according to the 2010-2018 pooled structural survey (sample).

From the comparison of the current concentration values for school neighborhoods and school catchment areas, Figure 78 shows a slightly leveling effect of the school catchment areas. In view of the limited unused mixing potential identified in the analyses for 2000/01, we ask ourselves whether the more socially strained Prélaz school district may now be better mixed in exchange with the Floréal school district. We also wonder, whether for the new focus areas in the polarized Entre-Bois and Couteau-Fleuri school districts the one-sided burdening of
individual schools can be avoided. And whether there is need for additional measures in the area of school route safety, school space planning, urban development or housing promotion. These questions could only be answered by a detailed analysis of complete current data on the pupils.

![Scatter plot of the relationship between residential and school segregation in the city of Lausanne (2010-2018).](image)

**Figure 78:** Scatter plot of the relationship between residential and school segregation in the city of Lausanne (2010-2018).

**Comments:** In contrast to the Figure, the concentration index is not based on the lower school pupils, but on the resident population between 25 and 65 years of age and their first language and educational level according to the pooled structural survey 2010-2018 (sample). For this purpose, street blocks per school were weighted with the respective number of 1st-4th graders residing there according to the HarmoS counting method (here with reconstruction of the catchment areas, see comment in the section Data availability in the appendix).

**Winterthur**

**Optimization of catchment areas in the 2000/01 school year**

For the city of Winterthur, the comparison of the reconstructed catchment areas in the school year 2000/01 with the different optimization scenarios (Figure 79) already shows a certain balance in the most restrictive scenario A (Figure 80). It is noticeable that the mixing in scenario A mainly affects the schools with low to medium concentration values. Even if the citywide leveling is only slightly reinforced, only scenario C brings some relief to the most burdened schools (right in the scatter plot). Again, the citywide leveling is noticeably stronger if interpenetrating catchment areas are enabled, in which case more schools in the upper third of the distribution benefit from the intermixing.
Figure 79: Maps of the reconstructed and optimized Catchment areas according to different scenarios for the city of Winterthur (2000/01).

Note: Compare comments on Figure 43.
Module 2: Room for maneuver for greater mixing

(0) Catchment areas 2000/01

(A) Optimization (max.dist. +5%, max.cap. +/-5%)

(B) Optimization (max.dist. +10%, max.cap. +/-5%)

(C) Optimization (max.dist. +5%, max.cap. +/-10%)

(D) Optimization (max.dist. +10%, max.cap. +/-10%)

(E) Scenario D with interpenetrating catchment areas

Figure 80: Scatter plots of the relationship between residential and school segregation with comparison to different optimization scenarios in the city of Winterthur (2000/01).

Note: Compare comments on Figure 44.

Analysis at the school district level for the 2000/01 school year

As in Basel, Bern and Geneva, the mixing potential in Winterthur is not only evident within the individual school districts, but also across school district boundaries. For the Veltheim-Wülflingen school district, a reinforcing
effect of school assignment can be observed regarding the effect of residential segregation on the school composition - like the Schwamendingen school district in Zurich and the Bethlehem school district in Bern. To allow for a stronger mix especially for the most burdened schools, the effect of permeable catchment areas according to scenario E will now be illustrated for the neighboring Winterthur school districts Veltheim-Wülfingen and Stadt-Töss (Figure 81). While a certain degree of mixing can be achieved in the case of the Langwiesen and Zelgli schools through the neighboring schools within the respective school district, a clear mixing potential across the district boundary is evident for the Neuwiesen school near the border. This triggers several area swaps, especially in the Veltheim-Wülfingen school district, but also with the Altstadt school in the Stadt-Töss school district.

Veltheim-Wülfingen school district (catchment areas 2000/01) / Optimization (scenario E)

Stadt-Töss school district (catchment areas 2000/01) / Optimization (scenario E)
Figure 81: Scatter plots and choropleth map for the concentration index according to reconstructed catchment areas and optimized catchment areas in scenario E for the school districts Veltheim-Wüflingen and Stadt-Töss (2000/01). Borders separating the school districts is marked with a red dotted line.

Note: Compare comments on Figure 46.

Figure 82 now shows evaluations for all individual catchment areas according to scenario A, enabling a comparison with scenario E illustrated with the example above. In addition, it becomes apparent that for the school most burdened in the school year 2000/01, Stofflerenweg in the school district Oberwinterthur, no mixing can be achieved, which also applies when all criteria are relaxed under scenario E (cf. data point with highest concentration value in Figure 80). This can be explained by the fact that the burdened areas near the Stofflerenweg school are turned away from the neighboring schools and the existing short school routes in the neighboring schools would have to be increased by significantly more than 10%. Possibly, instead of interpenetrating catchment areas, a joint catchment area with the neighboring school Wallrüti would enable a higher degree of mixing.

Oberwinterthur school district (catchment areas 2000/01) / Optimization (scenario A)

Seen-Mattenbach school district (catchment areas 2000/01) / Optimization (scenario A)

Stadt-Töss school district (catchment areas 2000/01) / Optimization (scenario A)
Preliminary analyses for the 2019/20 school year

The current choropleth map of Winterthur's resident population (Figure 83) allows a comparison with the corresponding map for the 2000/01 school year in Module 1 and thus provides information on the detailed sociodemographic developments that have occurred. These developments are better visible when aggregating these values at the level of school neighborhoods. This mainly reflects upgrading processes in the center including the area at the previously more burdened Neuwiesen school, with an otherwise relatively similar picture as in 2000/01.

Figure 83: Choropleth map on the concentration index for the city of Winterthur (2010-2018) and school locations in the school year 2019/20.

Comments: In contrast to Figure 40 (left), the concentration index is not based on lower school pupils, but on the resident population between 25 and 65 years of age and their first language and educational level according to the 2010-2018 pooled structural survey (sample).
This picture also corresponds to the reported transfer rates (chapter unequal access to education), where the most significant change occurs in the Stadt-Töss school district, with fewer transfers to secondary schools B and C and more transfers to the Gymnasium. A slight accentuation of the burden is evident in the Töss and Veltheim neighborhoods toward the city limits, as well as slight shifts between individual school districts in the Mattenbach neighborhood. In Oberwinterthur, there were changes in school space, but the more burdened quarters remain the same.

As in Geneva, we do not have data from the cantonal education statistics for the city of Winterthur, nor were we provided with municipal data on school catchment areas. Consequently, the current relationship between residential and school segregation cannot be examined in more detail in Winterthur either. In addition, since in the case of Winterthur no data on the social and ethnic composition of individual schools are publicly available, we map the composition of school neighborhoods in Winterthur as a function of the overall composition of the associated school district (Figure 84). This shows an extreme variance with regard to the school neighborhoods for all school districts. If the school districts are broken down into the subordinate neighborhoods (Figure 85), we see striking differences between the neighborhoods of Stadt and Töss, and - with somewhat more overlap - between Veltheim and Wülflingen. The school neighborhoods in the quarters Seen and Mattenbach show a greater variance, which also differs less from the value ranges.

Figure 84: Scatter plot of the ratio between composition per school district (2010-2018) and composition of their individual schools (2019) in the city of Winterthur.
The evaluations so far show that in Winterthur, apart from the Neuwiesen school, there is a similar relative distribution in the burdens of the school neighborhoods as back in 2000/01. In this respect, it can be assumed that the mixing potential continues to exist within the Veltheim-Wülflingen and Stadt-Töss school districts and that in the latter case a balancing across the neighborhood boundary between Töss and Stadt appears feasible. Due to the slight shifts and new distributions in school space, it would also be essential to check whether new mixing potential arises in the school districts of Oberwinterthur and Seen-Mattenbach, in the case of Seen-Mattenbach also across the school district boundaries with the districts of Stadt and Oberwinterthur. Should only a small amount of mixing be possible in certain areas, then additional measures such as school route safety measures, adjustments to the school space, and measures relating to urban development and housing promotion should be examined.

Preliminary conclusions

The preceding analyses for the 2000/01 school year show that there is considerable optimization potential not only for the city of Zurich, but also in the other larger Swiss cities studied. In Zurich, the optimization potential is most impressive at the Zurlinden school in the Limmattal school district, which can reduce its concentration value from 73 to 43%. The index of the schools Nordstrasse and Aegerten is reduced by almost 20 percentage points. For the other burdened schools, the reduction is rather between 10 and 5 percentage points. However, this is sufficient to bring eight burdened schools below or at least to the threshold of 40%. In Zurich, small-scale adjustments to the catchment area boundaries according to the most restrictive scenario A are sufficient for this, notably with unchanged school route lengths and school capacities.

Like Zurich, the schools with the highest concentration values can be relieved more in Basel and Bern, although a comparably high reduction as for the Zurlinden school cannot be observed in any other city. In Basel, also under scenario A, the more heavily burdened schools on the Kleinbasel side can be leveled out, albeit at a high level. On
the Grossbasel side, three schools can be brought close to or below the 40% threshold, and in the case of a relaxation of the specifications in terms of interpenetrating school catchment areas (scenario E), these schools can even be moved in the direction of the 30% threshold. In Bern, it is the two most burdened schools in the Bethlehem school district that - under scenario A - benefit by 10 percentage points from mixing. In the Mattenhof-Weissenbühl school district, a more burdened school can also be relieved by 10 percentage points. To exploit further mixing potential, it appears that in the city of Bern it is not so much a stronger penetration of the catchment areas as a greater leeway, particularly in the use of school space (scenario C).

In Geneva, too, the existing large differences between the schools can be balanced to a certain extent. In Geneva - despite a certain already observed equalization among the less burdened schools - an additional citywide equalization can already be achieved under scenario A, this time also including the more heavily burdened schools. For the then more burdened Champel school district, additional leveling to concentration values of 40% can be achieved, with a reduction of 14 percentage points in the most burdened school. In the less burdened school districts, schools can be leveled to concentration values of about 35 or 30%. In the case of the city of Geneva, a relaxation of the optimization conditions hardly holds any additional optimization potential.

It appears more difficult to achieve a citywide mix in the city of Lausanne, and this applies to all the scenarios examined. In scenario A, several of the most burdened schools can be relieved, but only in the range of about 5 percentage points. While this allows several schools to be brought close to the 40% threshold, many of the burdened schools remain closer to 50 than 40% despite the relief. This is especially true for the peripheral schools, Blecherette and Bourdonette, whose mix requires a greater margin, especially in terms of school commute length, than is provided for in scenarios B to E. In general, the somewhat loose settlement in Lausanne seems to make a stronger mix more difficult.

Winterthur has a similar starting position as Lausanne, with a relatively fragmented settlement area, although the schools back then, in the year 2000, had concentration values of no more than 40 percent. Scenario A shows only a weak leveling, especially for the more burdened schools. On the other hand, with a broader scope regarding the use of school space (scenario C), a stronger mix can be achieved, especially in connection with the possibility of more permeable catchment areas (scenario E). Under this scenario, all schools could be brought below or at least close to the 30% threshold, especially in the relatively more stressed neighborhoods of Wülflingen and Töss. In the Oberwinterthur school district, on the other hand, the Winterthur school Stofflerenweg, which was the most burdened at the time, proved not to be mixable under the tested scenarios A to E due to its relative peripheral location.

Despite the described mixing performance, however, in several cities more burdened schools stand out for which, due to their isolated location, (almost) no mixing can be achieved, at least not under the specifications of scenarios A to D examined here. In Zurich, this was the case for the schools Hohl/Kern, Grünau and Auzelg, in Bern the school Steigerhubel, in Geneva the school Aliborges, in Lausanne the schools Bourdonette and Blecherette and in Winterthur the school Stofflerenweg.

Based on the selected case studies, it was shown for each city which area swaps are possible for the purpose of mixing. Except for Zurich, the necessity of area swaps across existing school district boundaries was shown. This is true in Basel and Bern, where the school district boundaries in Kleinbasel and between Bethlehem and Bümpliz run through densely populated settlement areas. In Geneva, too, the intermixing of the then more burdened Champel school district comes about through an exchange with two neighboring school districts, although a possible exchange would also be desirable with the Acacias Bâtie and Satin-Jean Charmilles school districts for a citywide balancing. The same applies to Winterthur on the border between Stadt-Töss and Veltheim-Wülflingen. Even the improvements achieved in Lausanne relied on such area exchanges. While hardly any area exchanges were visible across the school district boundaries in Zurich, considerations were also made for Zurich in connection with school route safety and school planning, which would have increased permeability between differently composed school districts in the year 2000.
The preliminary analyses for the 2019/20 school year not only confirm that the current school catchment areas in the cities of Zurich, Basel, Bern and Lausanne continue to reproduce neighborhood segregation one-to-one. Due to the lack of possibility to reconstruct the catchment areas in Geneva and Winterthur, at least the variance of the school composition within school districts and neighborhoods can be shown. Even if the calculated concentration values cannot be directly compared with the 2000/01 values due to the deviating data base, for example, in Zurich, Geneva, Lausanne and Basel there are shifts in concentrations due to upgrading. We also perceive polarization tendencies on the edges of Lausanne and other shifts in Basel which are partially explained by changes in school space. The indices for 2019/20 also cannot be directly related to the analyses on composition and tipping effects, as the corresponding share values among pupils may differ significantly from the share values available here for the overall resident population. Particularly in more burdened neighborhoods, it can be assumed that the corresponding concentration values among pupils are likely to be significantly higher than the concentration values in the general population.

The preliminary analyses also suggest that more in-depth analyses using schools’ own data on pupils would most likely reveal untapped mixing potential. This is particularly true where schools with disproportionate pressures meet schools with disproportionately low mixing (as assessed in relation to neighborhood composition). While we can assume that certain schools in peripheral locations may still at present be difficult to mix, the analysis could suggest a two-pronged strategy of using school route safety and school space planning instruments, as well as urban development and housing promotion measures, in addition to an optimized assignment process.
The preceding analyses have shown that the school catchment areas of the cities studied here, Basel, Bern, Geneva, Lausanne, Winterthur and Zurich, largely replicate the existing segregation between residential neighborhoods also with regard to the composition of schools (Module 1). In addition, the algorithm developed for a small-scale optimization of catchment areas showed that school authorities have considerable room for maneuver to increase the mix between schools (Module 2).

In the present qualitative part, the current practice of school assignment and school space planning will be examined in more detail, based on expert interviews with representatives of the school authorities, at least for those cities where consent was given for such interviews. For the city of Zurich, the findings from the pilot study are reported, based on a joint interview with Barbara Grisch (President of the Letzi district school board) and Katrin Wüthrich (President of the Limmattal district school board) as well as on a separate interview with the school allocator Sabina Kaiser (Limmattal district school board). From the side of the Zurich school administration we also received written answers from director Michael Anders. In addition to the practice of school assignment and school space planning, we discussed challenges regarding mixing as well as requirements for a possible optimization tool.

Representatives of the school authorities in the cities of Bern and Winterthur also kindly made themselves available for expert interviews. In Bern, these were Ms. Rita Holzer (principal of cycle 1 at the Spitalacker/Breitenrain school site in the Breitenrain-Lorraine school district) and Jörg Moor (deputy head of the Bern school administration), and in Winterthur, Bettina Gasser (member of the Stadt-Töss district school board) and Christoph Baumann (president of the Oberwinterthur district school board).

The authorities responsible for the cities of Basel, Geneva and Lausanne were unwilling to provide any information. Yet the relevance of the issue should be particularly high in these three major cities, having the highest proportion of foreigners in Switzerland. In 2018, the proportion of foreigners was 38 percent in Basel, 43 percent in Lausanne and 48 percent in Geneva. In Basel, where children with German as a second language make up a majority in both kindergarten and elementary school, the head of elementary schools at the time, Dieter Baur, expressed his disinterest in the pilot study and the procedure developed, arguing as follows:

"Pupils are assigned to our schools where they live. We think this is a very good principle, with the risk that the mix is not so great. Still, we compensate this with different measures, and that's why we're not really interested in the algorithm, because we couldn't implement it at all."

(SRF 10vor10 2019; own translation)

Regarding the measures, the then co-principal of the Kleinhüningen school, Florian Ritter, commented in the same broadcast: based on a social index, his school received "a little bit" more support lessons beyond the proportionally distributed pool. When asked again to comment on this report, the current head of the elementary school, Urs Bucher, also reacted dismissively, citing a lack of resources, and a selected school contacted also declined to comment.

For the cities of Geneva as well as for Lausanne, the question of assignment appears to be a highly relevant issue in view of the different composition of the schools, which has also been the subject of much media coverage. The former head of the Lausanne office for primary and secondary education, Gérard Dyens, used his last days in office to evaluate in more detail one hundred applications for assignment received and speaks of a ‘liar’s poker game’ where organizational family reasons are invoked to get to the desired school (Roulet 2013b). According to the same media report, the assignment in Lausanne is mainly based on the place of residence of the parents, whereby the zoning maps ("cartes scolaires" - a non-official expression) are designed in such a way that the social mix is guaranteed. In Lausanne, for example, the residential district of l'Elysée was united with the more popular
Faverges, as were the children of the Bourdonette district with those of the better-off Languedoc. The same principle applies in Geneva, although the smaller size of the schools (on average 700 pupils per school compared to 1,000 pupils in the canton of Vaud) is assumed to reduce the mixing effect somewhat. In addition, exceptions to the catchment areas are often made by the school administrations themselves to balance out the number of pupils between the schools, for example if the demand in upgraded neighborhoods can no longer be met by the local school. When reallocations from the left to the right side of the river are necessary in Geneva, this often leads to objections from parents, according to the director of the elementary school office at the time (Roulet 2013b).

The current successor to Gérard Dyens in Lausanne, Barbara de Kerchove, also initially signaled interest in the study, pointing to a data-driven process to support school assignment and school transportation that had been implemented by the in-house geographer based on his own research (Emmanouilidis 2016; 2017) had already been implemented. However, only the geolocation of pupils and the organization of school transportation seem to be in the foreground, even though the same geographer points out in a co-authored research article the possibility and desirability of also taking social mixing into account (Emmanouilidis, Guex, and Bavaud 2016). An exchange would have been of great interest for this reason alone. However, the head of the service soon decided against any involvement in the study with reference to other projects and scarce resources and left all further inquiries unanswered during the entire project period - including the request for information on the current practice of school assignment and school space planning.

In response to a request for further information or comments on the analyses presented here, the director of the Geneva Office for Educational Research (SRED), Martin Benninghoff, was also unable to provide any information, citing a lack of competence as the reason. Also, the cantonal office of elementary education, which is responsible for the assignment to schools, only stated that the assignment of pupils depends on the spatial proximity to the school.

In view of the lack of willingness to cooperate in the cities of Basel, Geneva and Lausanne, we will do without a more in-depth analysis of the assignment procedure and school space planning for these cities and continue with the descriptions of the cities of Zurich, Winterthur and Bern in the order mentioned.

Zurich (pilot study)

Responsibilities and criteria for school assignment in the city of Zurich

The Elementary School Act of the Canton of Zurich stipulates that in school communities, the school administration is responsible for allocating pupils to schools, while school administrators are responsible for allocating pupils to classes within their schools (Kanton Zürich 2005, §42 and §44). In the subordinate organizational statute of the city of Zurich, the task of assignment to schools is explicitly attributed to the presidents of the district school boards (Stadt Zürich 2006b). In fact, the director of the school board, Michael Anders, confirms that the school administration and also the elected councilor heading of the school and sports department do not have any legal competences in the field of assignment of pupils.

In the regulations on the assignment of pupils (Stadt Zürich 2009) also stipulates that pupils at the kindergarten, primary and secondary levels are generally required to attend school in the school district in which they reside, although the presidents of the district school authorities concerned may, under certain conditions, agree on an allocation across the school district boundary.

The following principle applies to the assignment for all school communities in the Canton of Zurich:
"In assigning pupils to schools and classes, attention shall be paid to the length and danger of the school route and to a balanced composition. Particular consideration shall be given to the ability and social and linguistic background of the pupils and to the gender distribution."

(Art. 25 para. 1, Elementary School Ordinance, Canton of Zurich, Decision of the Government Council of June 28, 2006; own translation and own emphasis)

While the cantonal ordinance refers the requirement of a balanced composition to the assignment to both schools and classes, it is noticeable that the corresponding article in the assignment regulations of the city of Zurich applies the principle of balance only to the formation of classes (the second sentence only mentions classes):

"In assigning pupils to schools and classes, attention shall be paid to the length and danger of the route to school and to the balance of class sizes. Classes shall be composed as equitably as possible, considering in particular social and linguistic origin, ability and gender distribution."

(Art. 4 Regulations on the Allocation of Pupils of the Elementary School of the City of Zurich, resolution of the Presidents' Conference of May 26, 2009; own translation and emphasis)

While the two cited articles describe the aspects of a balanced composition in more detail, the maximum school route length or the assessment of dangerous school routes, which are also relevant for school assignment, are not regulated by law in the canton of Zurich. In a summary report on the case law in Switzerland, Schweizer and Regli (2014) state that school routes of up to 30 minutes and 1.5 kilometers are generally considered reasonable for primary school pupils. For the assessment of the dangers in road traffic, Schweizer and Regli (2014) mention the following generally considered aspects: Availability and design of sidewalks and footpaths, traffic volume and share of heavy traffic, speed, type and number of crossings (pedestrian crossings, traffic islands, traffic lights), complexity of intersections, lighting situations and clarity, as well as road works, etc. An urban environment that requires crossing the road several times can be considered reasonable, provided that all difficult crossings are secured with traffic lights.

According to media statements from the cantonal elementary school office, the rule of thumb in the canton of Zurich is that a school route of 1 to 1.2 kilometers is considered reasonable for kindergarten children (vgl. Fassbind 2014). However, in a city such as Zurich, a school route of one kilometer is not necessarily considered reasonable if the child must cross heavily frequented streets. Parents have the possibility to ask the local school board for reassignment or for measures or, in case of conflict, to appeal to the district council. Possible measures include the use of a school bus, the assumption of subscription costs for public transport, an escort service, pilot services or pedestrian overpasses on dangerous roads. In addition, the introduction of 30 km/h speed limits is of great importance today (vgl. Fassbind 2014). The school authority of the city of Zurich specifically states for pupils of the lower school that walking distances of more than 1.4 km is without further proof considered to be very burdensome, constituting a claim for school travel relief (Stadt Zürich 2006a).

When asked about the different wording of the assignment principle in the cantonal elementary school ordinance and in the municipal regulations, President Grisch (Letzi district school authority) explains that in the event of a contradiction, the higher-level cantonal law naturally applies. Where possible, her district school authority already takes the criteria into account when assigning to schools, and not only when assigning to classes. President Wüthrich (Limmattal district school board) also considers her school district to be large enough to ensure a certain mixture between the schools. However, it is also important to both presidents that siblings can attend the same school if possible and that children from kindergarten to 6th grade can stay in the same 'school unit' and in the
same 'system' (gradual introduction of day school throughout the city). In addition, children should be assigned together with other children from the same street as far as possible, so that the children do not have to walk to school alone. Both presidents fear that rigorous efforts to increase mixing could make it more difficult to grant these - quite justified - requests.

**Practice of school assignment in the Zurich school districts**

The district school boards of the city of Zurich access the central database of the School and Sports Department, in which every locally resident child is included (from birth). This database is fed with data from the residents' registration office regarding name, street and house number, date of birth, gender and nationality and is operated with the "pupil management" software. For the current assignment to schools and classes, the database is supplemented with further information on the children to be allocated. This additional information is collected by means of a form sent to the parents for the kindergarten entry, or to the previous teachers for the upcoming transfer to the next higher school level. For the transfer from kindergarten to the first grade, this includes the first language (language group and in detail with regard to home language and culture), German language skills (1-3), the amount of care required (1-3), performance (1-3), any special needs, as well as information that could be relevant for class formation (career decisions, relocation of pupils, transfer to private school, etc.). In 2019, this form for teachers was replaced by the web application "SKS" (standardized criteria for pupil assignment), whereupon this information from the teachers flows into the pupil management database of the district school boards (Schulamt Stadt Zürich 2019). The assignment criteria are based on the supra-disciplinary competency model from the new ‘Curriculum 21’ agreed by the German speaking cantons. They were developed by the school administration together with the responsible persons from all district school boards. For the transfer to the first grade, the following information is specifically requested: subject competence (1-3), self-competence (1-3) and social competence (1-3), any support needs as well as comments from the teachers regarding class formation (career decisions, relocation of pupils, transfer to private schools, etc.). In addition to this information, the school boards supplement the database with information regarding parental assignment requests.

School assignment and class formation is a very time-consuming process. For the 2017/18 school year, according to President Grisch, a good 1,800 children were assigned to new classes in the Letzi school district. For the assignment to the schools, initially the school catchment areas are relevant. The catchment areas are defined in an Excel document by assigning the corresponding school to each street and house number. This assignment is based on the school routes (distance, type of roads), the number of children and the capacity of the surrounding schools. This assignment is regularly reviewed and periodically adjusted due to construction activity or demographic changes, with the focus here being on matching the number of pupils with the school capacities, which is confirmed unanimously by both presidents interviewed and also by the school allocator Kaiser.

The pupil management database and the assignment of the streets are linked via the residential addresses. Thus, an initial technical assignment of the children to be enrolled to the schools is made. This shows whether adequate class sizes result for the planned number of classes per school, or whether certain streets located in the border area must be shifted from one school to the other in order to balance the class sizes. In the case of major changes in catchment areas, resulting for example from a newly constructed school, school allocators can seek advice from experts from the Geomatics Department of the City of Zurich for the demarcation of boundaries to determine the best spatial allocation (School Allocator Kaiser). However, these technical assignments do not consider concrete circumstances (siblings, approved assignment requests from parents, ongoing support measures, etc.). The technical assignment is therefore only a first basis for the school allocators for the concrete assignment of the individual children to the schools (President Grisch). For example, in the case that some of the pupils must be

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15 For the transfer from the lower to the middle school, the German and mathematics grades are recorded, self-competence (1-3), social competence (1-3) and any need for support. When transferring to the secondary level, the selection decision is recorded (secondary A or B), the German and mathematics grades, the assigned level (I-III or dispensation), self-competence (1-3), social competence (1-3) and any support needs.
assigned to a different school for the next school level, care is taken that several pupils of the same class can change together (school allocator Kaiser).

Classes are then formed within the schools based on the school assignment. For this purpose, lists of the assigned children, including recorded assignment criteria and comments, are issued in the pupil management database for each school and forwarded to the school principals for final assignment to the individual class teachers. In doing so, the school principals ensure in their "very own fundamental interest" that the classes are as mixed as possible - or consider carefully whether a setting with more strongly supported children in a smaller class makes sense (President Grisch).

At no point in time are the assignment criteria recorded for class formation accessed for determining school catchment areas, even though the information is already available in the central pupil management database. At the most, these data are accessed selectively when assigning individual pupils. For example, in the case of ongoing support measures, the school principal concerned is consulted to make the best possible assignment decision (school allocator Kaiser).

**Practice of school space planning of the city of Zurich**

The street allocation described above results in the catchment areas of the schools, which form an important basis for the preparation of pupil forecasts for the next eight years by the school space planning office of the city-level school administration. The school space requirements strategy ('Raumbedarfsstrategie Schulen') derived from this, which shows the emerging space requirements, is updated annually. This is based purely on pupil numbers without concern for balanced composition of the schools. Both interviewed presidents of the Letzi and Limmattal district school boards consider this report an important planning aid. In it, the number of required classes is shown in coordination with the available space per school. In addition, this information is summarized for individual contiguous quarters, each with several schools. President Wüthrich compares the figures of the specialist office with her own figures in the pupil management database and thus determines for which schools the specialist office assumes additional pupils due to new buildings. Since the figures of the specialized agency are based on the stored catchment areas, possible uncertainties (augmenting deferrals, families moving away before school entry) and possible necessary area adjustments must also be considered in the own planning, according to President Wüthrich.

To obtain more reliable forecasts, the adjustments made to the catchment areas are also updated annually in the list of streets and stored for the school board. Thus, in case of emerging changes, the question arises whether certain classes have to be relocated, whereby such relocations would also affect the teaching staff (school allocator Kaiser). In contrast to the Limmattal school district, the Letzi school district, which is experiencing particularly high growth, relies less on the school-specific data in the report than on the summarized figures for the larger school areas (President Grisch). These areas are separated by larger roads, but within the spaces, school commutes are feasible. Thanks to the relatively high compactness of these spaces, the school district is very flexible in adjusting catchment areas and "it almost always works out." In contrast to the Limmattal district school board, their school board therefore does without the time-consuming annual updating of the list on the street routes and only adjusts them periodically.

With the newly introduced "neighborhood analysis", the school space requirements in the neighborhoods will be determined regularly in the future, in each case with an overall view on several schools, pavilions, and necessary rentals, and considering the necessary operational and financial measures. Possible measures include outsourcing, multiple uses or the adjustment of school catchment areas. For the "balancing of interests by the elected city council", the involved city departments have developed a catalog of criteria, which takes into account the building and zoning regulations, inventories, building condition and catchment areas (Stadt Zürich 2019a). The agencies involved include the relevant district school authority, the school office, the sports office, the office for real estate, the office of urban development, property management office and the environmental office. The focus is on the long-term coverage of demand in a neighborhood, with various expansion scenarios being compared.

President Grisch (Letzi district school authority) represents the district school presidents in the municipal delegation (building construction, school and sports, finances) introduced for this purpose and she was also
involved with her school district in the pilot for the "neighborhood analyses". In fact, she observes that the district school authorities also raise concerns about the mix in this context. After all, an expansion or a new school building location always has an impact on the composition of the schools. According to Michael Anders, director of the school board, on the other hand, the main issue is finding enough school space in a suitable location - i.e., near the pupils - and whether the sites are suitable for school uses. The question of a good mix of schools and classes and the associated allocation of resources is, in his view, not only a question of assignment or school space planning, but also a question of urban and spatial planning, housing policy and thus a socio-political one. In addition, the director of the school administration regards social cohesion in a neighborhood as an important aspect to be considered as well.

Regarding his personal attitude, director Anders refers to a basic paper of the "Städteinitiative Bildung" (section of the Swiss Association of Cities) and the classic work on the "theory of justice" by John Rawls cited therein (1975). The quotation states that it is "[not] unjust that persons are born into society at some particular position. These are simply natural facts. What is just and unjust is the way that institutions deal with these facts" (cited in Städteinitiative Bildung 2016, 4). Interestingly, in the same basic paper cites James Coleman (1966), the discoverer of peer effects in the context of segregated schools, supplemented by recommendations on the "positive discrimination" programs practiced in Switzerland in socio-spatially disadvantaged schools (e.g. QUIMS in Zurich and REP in Geneva).

**Challenges in mixing schools in the city of Zurich**

In fact, for the two interviewed presidents of the Limmattal and Letzi district school authorities, the primary credo for assignment to schools is that "children go to school where they live". Within this guideline, it is important to them that the criteria regarding the route to school and the balanced composition are adhered to. However, according to President Wüthrich (Limmattal district school board), the horizon always remains the "neighborhood school". In particular, the two presidents vehemently oppose rigorous mixing attempts with school transports, for example to the privileged Zurichberg school district. The presidents are also indignant about the idea of having to ascribe a positive or a negative characteristic to individual children and then having to exchange them between schools to compensate. President Grisch has even been asked by a school in her district for exactly such a selective exchange, which was completely out of the question for her. It would be better to invest in the development of the schools within the existing catchment areas, she is convinced.

President Grisch observes that schools that can adapt to educationally disadvantaged families can become quite strong. The district school board can support these schools with additional resources in consultation with the school principal. In addition, schools can develop good self-confidence and innovative projects through QUIMS programs: "If schools are convinced that they are a good school and broadcast that, then they are" (own translation). President Wüthrich agrees but points out that there are also teachers who have resigned themselves to the fact that their pupils "are just no good for anything" (own translation). It is therefore necessary to bring teachers to believe in the pupils they teach. President Grisch adds that it is important to teach the children self-confidence and self-efficacy, then they would make their way, "even if it takes a loop more than with other children" (own translation). In addition, both presidents observe that an increasing proportion of more educated families in the schools can also be a challenge, which can be seen in several upgraded school areas. While these families often moved away before enrolling in school in the past, they are now staying; at the same time, the area is attracting new better-off families. These families now approach the schools with expectations and feel that if they are contributing to the mix, the school owes them something. Yet they are considered all of equal value and must be taken equally seriously by the teachers and the school board (President Wüthrich). At the same time, the resulting mixture is of course also good and healthy, the school must simply be able to adjust to it over time. In this respect, President Grisch prefers such a natural process of mixing, within which the school must react, instead of forcing an artificial mixing at one stroke. To be sure, she also understands the great importance of, for example, peer "language role models" who enter the school classroom with the mixing. "But if you're then the family that provides the child with the good language role model, that's a challenge for the school and also for the family."
However, President Grisch is more concerned about areas that are in a "latency phase". In such areas, developers are planning major changes with replacement buildings. However, the time horizon is unclear. In the meantime, apartments are only rented on a temporary basis. Those who can afford it move, and the housing estates are increasingly inhabited by socially disadvantaged families, who often do not stay long. Here she would like to promote school mixing. However, this possibility often does not exist due to the location (roads, accessibility of neighboring schools, etc.). "In addition, I would then have to assign children who would naturally come to another school there, in order to give children from the school in question to another school" (own translation).

President Grisch therefore considers urban planning and housing subsidies to be of central importance for mixing. In particular, she appreciates the mix that building cooperatives bring to her school district. Cooperatives would bring a good mix per se, since they have that in their statutes. In addition, it is central that urban development policy pays attention to well-mixed residential areas in planning. In the view of President Grisch, the city of Zurich does this well in principle. At the same time, President Wüthrich points out the phenomenon of displacement and that urban planning is still not very aware of the effects regarding the composition of schools. President Grisch thinks that displacement must be prevented, but that new non-profit housing must also be created. These would no longer be the same people, but a good mix could be created.

Possible requirements for an optimization tool for school catchment areas in the city of Zurich

Only after the discussion summarized above on the personal assessments and experiences regarding mixing, the functioning of the algorithm was explained to the interviewees, as well as the resulting maps and scatter plots. Fortunately, many of the concerns expressed could thus be dispelled:

- These are small-scale adjustments to catchment areas, largely within school districts: no school buses are required
- Individual pupils or families are not selected and moved between schools; rather, street blocks along area boundaries are moved and areas remain contiguous (still "neighborhood schools", but with good mixing)
- If optimized catchment areas for 1st grade are also taken into account in the assignment to kindergartens, pupils can remain in the same 'school unit' from kindergarten to 6th grade as before
- The optimization is based on a scientifically justified index and the algorithm and the parameters taken into account are documented transparently
- Strong equalization is possible within school districts without necessarily requiring additional capacity or longer school commutes
- Balancing between schools also makes the reallocation of an area seem less dramatic, and the mixing of schools may also help to mix residential neighborhoods more in the future

President Wüthrich (Limmattal district school board) stresses again the importance of not selecting individual families but shifting areas based on a well-founded index. The pupil management software could evaluate the pupil assignment criteria from the SKS web application with a view to achieving greater mixing between schools and suggest possible adjustments in the catchment areas. On this basis, assignments could then still be made carefully, considering specific circumstances and individual pupil circumstances. President Grisch (Letzi district school board) is skeptical that the optimization would mean that a street block would be assigned to this school one year based on the composition of the currently enrolled cohort, and the next school year a differently composed cohort would be assigned to another school. President Wüthrich also thinks that one should not exaggerate and always enforce the absolute best mix. We then pointed out the possibility of considering the socio-demographic composition of the last three years for the calculation of the optimized catchment areas, similar to the present study.

There would therefore be no reason for catchment areas to fluctuate more in the future than they do today. De facto, individual street blocks already change today simply because of the uneven distribution of pupils in space.
and over the years, without this necessarily being tracked in the catchment area maps. In all these cases, the optimized catchment areas would simply add to the mixing. New or totally redeveloped settlements could be marked to reflect only the current socio-demographic composition here.

At least with the changeover to optimized catchment areas, however, there would also be a larger one-time reconfiguration of catchment areas. In fact, President Grisch confirms that even newcomers know exactly where their neighbors' children go to school. This is clear from the assignment requests. In addition, there are also parents who ask the district school board how high the quotas for the gymnasium are in different schools - to which she refers to the education statistics. Already today, reallocations of entire areas lead to quite a bit of turmoil. As both presidents confirm, communication is crucial in these cases. It is necessary to announce a change and, if necessary, to indicate the scope of the adjustments.

It would also be important to both presidents that the mixing can then also be implemented consistently and does not fail, for example, due to the available school space. However, since the analysis examined here shows a high mixing potential even with the given school spaces, these concerns can also be dispelled.

Finally, President Wüthrich points out that QUIMS money is currently awarded to schools with blended indexes above 40 percent. To avoid that the mixing leads to a loss of these funds for these schools, these funds should be able to be used more flexibly.

**Winterthur**

Due to the similarities in the school organization and in the cantonal requirements, the description of the city of Winterthur follows directly after that of the city of Zurich. The city of Bern is discussed in the after-following subchapter.

**Responsibilities and criteria for school assignment in the city of Winterthur**

As is the case for all Zurich school municipalities, the school authority of Winterthur is responsible for the assignment of pupils to the (regular) schools, while the school principals are responsible for the assignment to classes within their schools (in some cases, their school units include several primary school locations). Although dissolved in 2022, at the time of the study, the district school boards were responsible for school assignment according to Winterthur's rules of procedure for the elementary school (Stadt Winterthur 2010). They were responsible for implementing the cantonal and municipal guidelines together with the school administrators. Unlike in the city of Zurich, school assignment is thus not explicitly attributed to the presidia of the school boards at the level of the school districts. However, Winterthur is also subject to the requirements of the Ordinance on the Elementary School, as described in the previous subsection, according to which a balanced composition in terms of ability, social and linguistic background of the pupils as well as gender distribution is considered in the assignment to schools and classes (Art. 25 Para. 1, Ordinance on the Elementary School of the Canton of Zurich).

In contrast to the city of Zurich, Winterthur does not have a corresponding city-wide regulation for the implementation of the cantonal requirement regarding balanced composition, neither in terms of school assignment nor in terms of class formation. Instead, Winterthur's organizational regulations for the elementary school are limited to the following specification:

"*Pupils generally attend kindergarten and school in the school district in which they reside.*"

(Art. 12 para. 1, Organizational Regulations for the Elementary School in Winterthur of January 16, 2018; own translation)

At the request of parents or for pedagogical, organizational or disciplinary reasons, a change of district can be initiated, whereby in the event of a dispute between two district school boards, the central school board decides - as is further stated in the same article. Furthermore, the district school boards are given the authority to decide on
measures if pupils cannot make their way to school independently, which includes the initiation of traffic measures or the use of a pilot service, as well as the approval of a school transport. When deciding on the transport of pupils, the age and state of health of the pupil, the length and difficulty of the journey to school, as well as the danger of the route must be considered, whereby different distances on foot are decisive regarding the length of the journey to school depending on the school level. For kindergarten the distance is 1.6 kilometers, for first grade 1.8 kilometers, with intermediate steps up to 5 kilometers for secondary school (if the use of a bicycle is deemed reasonable).

**Practice of school assignment in the Winterthur school districts**

The school assignment process in the city of Winterthur is similar to that in the city of Zurich. In the registration form for kindergarten, information on the first language and German language skills is requested citywide, while for the transition from one level to the next, the teachers provide information on the needs of the individual pupils, such as German as a second language and further support needs and recommendations regarding the assignment. This list also includes accompanying measures such as day care, speech therapy and other therapies, etc. as well as the status ISR (integrated special education under the responsibility of the regular school) or ISS (integrated special education under the responsibility of a special school). In contrast to the city of Zurich, these additions are entered on Excel lists and, apart from German language skills, no competencies are queried in the sense of the city of Zurich web application "SKS".

For the assignment to school units, as in the city of Zurich, a rough assignment is first made based on provisional school catchment areas to ensure that the class sizes and the allocated full-time units can be adhered to. The interviewed president of the Oberwinterthur district school board, Christoph Baumann, proceeds in such a way that he views a map with pupils as points in the school administration program Scolaris and draws a previously proven polygon over it and adjusts it until the class sizes are balanced. In this way, he can react promptly to the current distribution of pupils in the corresponding cohort or to new construction activity, especially in growth areas. In the converted former industrial area of Neuhegi, the children are distributed among the three nearby schools, while in the planned new development of Tegerloo, at least for the lower school, there is no alternative school location apart from Guggenbühl. First and foremost, it is always about the reasonable distance. Accordingly, this rough classification is not about "a narrowly defined limit", but it is about having an overview of the number of pupils and "clarity regarding the class formations in the schools" (President Baumann, own translation). Also in the school district Stadt-Töss the boundaries of the catchment areas are partly handled flexibly. It could be that a kindergarten is already full and therefore children living in the border area are assigned to a kindergarten of the neighboring school unit (school board member Bettina Gasser). Or there are areas along the border from which the children are assigned to different kindergartens from year to year.

In the following step, the individual cases are then looked at and it is checked whether it is possible to assign someone to another school if this makes sense for balancing the schools. Based on the above-mentioned list, there is the possibility in this step to distribute children with special needs to the different schools, taking similar needs together where it makes sense. Within the schools, it is also possible that school principals specifically create integration classes grouping special needs pupils (mainly ISR) together to enable the best possible cooperation in curative education (President Baumann).

In the school district Stadt-Töss as well, the identified need for support (especially ISR) is considered in the school assignment (school board member Gasser). With these children, allocated resources (full-time units) are also tied up, and so one must make sure that the full-time units per school are adhered to. Children in need of support could also be assigned across areas: For example, two children from different school districts were assigned to a common kindergarten, and thus the 40 percent care each received from a special education teacher was combined into 80 percent care (school board member Gasser). In addition, when allocating schools, parental requests are considered whenever possible, regarding the care of the child at a second location, the assignment of siblings to the same school or the organization of communities of interest among themselves.
Practice of school space planning of the city of Winterthur

According to President Baumann, there is a close exchange with a company that is entrusted with the annual school space planning. All approved and planned new buildings are considered and summarized in a school space plan until 2035. However, this would also expose the great challenges for the city of Winterthur to cover the strongly increasing demand for school space. The high demand leads to the situation that the construction of new schools is postponed if sufficient school space is still available. The Oberwinterthur school district, for example, is receiving a new secondary school building for 24 classes, which represents a significant increase in size. Since a previous secondary school is moving to this new location, a school building is being freed up which can now be used to meet the needs of the lower and middle school. However, the schools’ location is set, and it cannot be moved elsewhere. In this respect, the possibilities for control are limited. A forward-looking view is also needed for school building extensions and pavilions, which require a planning period of around ten and three years respectively. In response to the question of whether, in view of this fact, any attention at all can be paid to mixing, school president Baumann says: "No, this can hardly be taken into account in construction projects, but we do have an influence on good mixing when assigning schools. We’ve already built a lot of new school buildings in recent years, and we’ve had pretty big tasks with that" (own translation).

There are also many new settlements in the Stadt-Töss school district, especially in the Sulzerareal and Vogelsang near Tössfeld. Since the existing classes there already hold 26 children, a new mixed-age class with 1st and 3rd graders will be formed as an exception (school board member Gasser). Regarding the flexibility to open new classes, school board member Gasser considers the possibility to be given in principle, even if the room for maneuver appears as rather tight. The construction of new pavilions is always associated with cost issues and is the responsibility of the school department, as is the construction of new school buildings. For school space planning, the school department is in regular contact with the school boards and school principals. It is difficult to reliably estimate long-term developments in this area. In the newly built Vogelsang housing development, for example, the assumption was that there would be many families, but it was not until they actually moved in that it became clear how the age groups would be distributed.

Challenges in mixing schools in the city of Winterthur

Bettina Gasser, the interviewed member from the Stadt-Töss district school board, is the head of the school boards’ "assignments" working group, which was founded in May 2020 to deal with the issue of mixing. In this activity, and without being directly involved in the process of school assignments, it becomes clear to her that school assignments are a complex matter. Basically, the guidelines of the cantonal education department have to be adhered to, which is already challenging. These criteria ensure that similar conditions are created for the pupils. These include balanced class sizes, gender distribution, a balanced ratio of stronger and weaker pupils, the distribution of pupils with special needs, the length of the school route and school route safety. Foreign language skills are also taken into account in the context of special needs by distributing ‘German as a second language program’ pupils evenly among the classes. At present, the length of the route to school and the neighborhood are weighted more heavily in school assignment. But of course, the pupils have to be allocated to the schools in such a way that the parameters regarding balanced class compositions are also adhered to (school board member Gasser).

The school district Stadt-Töss is a long school district, with the schools with the lowest proportion of foreign speakers at one end and the schools with the highest proportion at the other end. Here, the children would have to take the bus for the mixing, but this was not really wanted - the children should be able to make their way to school on foot (school board member Gasser). When asked about the clear differences in the composition of the population along the border between the City and Töss quarters within the school district, school board member Gasser agrees that there is room for maneuver in this area to achieve greater mixing, for example in the neighborhood between Eichliacker and Tössfeld or between the Brühlberg and Rebwiesen school buildings. Accordingly, on the one hand there is a noticeable political responsibility to even out the large differences - a
concern that is certainly also voiced by school principals. On the other hand, the mood among parents is mixed and fears quickly arise. It is understandable if families whose children are already together in the neighborhood and go to daycare, playgroups and kindergarten together want to stay together. These grown structures would also have a strong integrative character (school board member Gasser). One would not want to tear apart these neighborhood communities (homework help, lunch tables, other care). On the other hand, the studies on mixing speak a clear language. So there is room for maneuver that has to be checked (school board member Gasser).

When asked about personal priorities in school assignment, the president of the Oberwinterthur district school board emphasizes that he is concerned with balanced class sizes, a balanced gender ratio, and with distributing children with special needs among the various schools. With the list for foreign languages and other support needs, care is taken to form balanced classes in this regard. At the same time, however, it is difficult to balance the allocation of children to the kindergartens or to the 1st grade via roads with heavy traffic or long distances. At the Guggenbühl school, the pupils already must cross busy roads via pedestrian crossings with traffic lights, or a traffic pilot is used elsewhere on Frauenfelderstrasse to cross the road. Balancing is often not possible due to the length of school routes, for example between the better-off Rychenberg district and Wallrüti, where the distances are long. Things are better in the Hegi district, for example, where there are three schools within a possible distance and where the school administrators can assess the family background on based one residential address. Thus, on the one hand, the children with higher educational backgrounds from the cooperative housing are distributed to the schools, but so are the children from the municipal social housing assistance. The new Neuhegi district, on the other hand, is relatively self-contained, with isolated interfaces with the neighboring schools in the upper part. The president of the district school board Oberwinterthur also refers to the social monitoring of the city of Winterthur, which makes it possible to view the social burden as well as the planned developments in the various parts of the neighborhoods in detail. The knowledge about so-called burdened neighborhoods is thus clearly available in the district school board and can be considered in school planning. For example, it shows that the situation in the Töss district (Stadt-Töss school district) is quite different from other parts of the city, while the subunits within the Töss district are also very different from one another. But also in the school district Oberwinterthur there is a dispersion between the single-family house district Rychenberg with two primary schools and the district Guggenbühl and Wallrüti, where a particularly high percentage of people with low educational backgrounds and foreign languages live due to the cheap housing. As far as possible, balancing will be implemented here. While Zinzikon is well mixed, the increased needs in the Guggenbühl and Wallrüti neighborhoods are met from the 1st primary onwards by smaller classes and allocation of resources for German as a second language programs and remedial education and later with youth work and leisure activities. Also in the school district Stadt-Töss it is the case that the social background is mainly taken into account in the allocation of additional full-time units to the schools, which is based on the social index calculated by the canton at the level of the school districts (school board member Gasser).

In response to the question of whether longer school routes or more permeable catchment areas could also be accepted for the sake of mixing, school president Baumann says that he would in principle go as far as the defined maximum distances, but that the hills in Winterthur would make greater mixing more difficult and that it is almost a matter of topography which schools are attended by whom. Winterthur differs from the densely contiguous residential quarters that can be found in the city of Zurich, for example. President Baumann also already thinks in terms of permeability: there are certain streets that can be flexibly divided between two different schools. However, the knowledge of the local schools is always important for the assignment: "They are in good contact with the families, perhaps they already had three children with us, and so the contact to the foreign-language families is already established" (President Baumann, own translation).

School board member Gasser in the Stadt-Töss school district could also imagine longer school routes in principle, at least where they are short today, as in Tössfeld. It would be justifiable to improve the mix by assigning the children to the second closest school. School board member Gasser thinks that there is no fundamental right to be assigned to the school that is perhaps only two streets away from the place of residence. A certain spaciousness in
thinking is necessary here, and parents get used to it when it is normal that different schools are available for selection. In some areas, it is already the case that there is no certainty as to which school you will be assigned to. Personally, school board member Gasser also thinks that the catchment areas should be more interspersed, because the more evenly the mix is achieved, the more parents' fears can be reduced that their child will be enrolled in a class in which foreign languages predominate. Ultimately, the question is what the intermixing means for the individual neighborhoods (school board member Gasser, own translation): “Do these neighborhoods already intermix anyway, or are entirely new spaces being created here?”

Asked about the possibility of equalization at the school district border between the city quarter and Mattenbach, school board member Gasser says that this should also be examined. For example, until summer 2021, the Frohberg kindergarten belonged to the Tössfeld school unit, which was close to the border, and from where the children transferred to the Tössfeld, Altstadt and Mattenbach (Schönengrund) schools, depending on the residential neighborhood (school board member Gasser). However, the boundaries of the school districts are currently respected; for a change of school district, parents needed a well-founded request.

In principle, school board member Gasser could also imagine alternative school assignment procedures. While initiatives for a free choice of schools do not find political majorities, she finds the data-based assignment procedure presented in this study worth examining. She also finds the idea of merging different schools with a common catchment area interesting. For example, a common catchment area for the Eichliacker and Tössfeld schools would probably allow for a more balanced mix within the intersection between the two schools. In addition, school board member Gasser wonders whether schools should receive more relief through additional full-time units according to the social index. Asked about the role of municipal and cantonal school policy in increasing the urban mix, school board member Gasser sees the need for a sensitization process as given. The topic is still not discussed enough in Winterthur and causes many fears. She also thinks that the requirement for mixing should be demanded more strongly at the cantonal level, just as many things in the school sector are already regulated at the cantonal level. In Winterthur, it will also be exciting to see how the reorganization of the school authorities may offer the opportunity to adapt existing processes.

**Possible requirements for an optimization tool for school catchment areas in the city of Winterthur**

When asked about the added value of a data-based procedure for determining the catchment areas, school president Baumann says that he has the necessary knowledge about his neighborhoods so that he can plan for a good mix as well as possible. Because of the clearly structured neighborhoods with existing school sites, he says he needs this less in his situation. Even though he has only been in office for two and a half years and does not live in Oberwinterthur, he knows which neighborhoods are inhabited by whom. For situations like in Zurich or in cities that are densely built-up, exchanges across school district borders would certainly make sense. However, this is less true for Oberwinterthur, since assignment is almost geographically predetermined (President Baumann).

For the interviewed school board member Gasser personally, it would be important that the possible room for maneuver is examined in depth and exhausted based on the present study. On the one hand, in favor of equal opportunities, and on the other hand, because - according to the principles of the study - everyone would be served by a better degree of mixing - if it does not lead to a loss of QUIMS support. In this respect, she also sees a clear political mandate. School board member Gasser therefore sees a need for action, but she also sees that quite a lot of parameters already must be considered. From her position in the school board - she is not involved in the school assignment - she sees the potential of an auxiliary instrument in the proposed procedure. A more in-depth discussion of the procedure could lead to existing mechanisms being questioned. However, clear guard rails will still be needed and also people behind them who know the circumstances on the ground. People cannot be replaced, but the procedure can be used as an aid.
Responsibilities and criteria for school assignment in the city of Bern

The elementary school law (Kanton Bern 1992) merely stipulates that every child attends the public school at his or her place of residence, although children may attend the school of another district or municipality for important reasons (art. 7 paras. 1, 2). The school administrations are responsible for the pedagogical and operational management of the elementary school (Art. 34, para. 2). In the city of Bern, school assignment is regulated as follows:

"1 The school principals of the school district shall allocate the children and young people to the individual school sites. They strive for a social mix in the schools.
2 In making assignments, attention shall be paid to safe and age-appropriate routes to school and to balanced class sizes."

(Art. 6 par. 1 and 2, School Regulations of the City of Bern of December 3, 1998, amended in accordance with the municipal resolution of 28 November 2010; own translation and emphasis)

Compared to Zurich and Winterthur, the social mix is thus raised to the central assignment criterion by the city of Bern itself, supplemented by the requirements for school routes and class sizes. Moreover, in the canton of Bern, it is not the supervisory school boards (‘school commissions’) that are responsible for assignment, but the school principals within the school districts. The school commissions are responsible for determining the locations for the upper grades and the other offerings (Stadt Bern 1998, Art. 34). The six Bernese school districts are divided into three to four so-called school sites (groups of school buildings), in which the respective school site principal manages the corresponding school buildings and kindergartens or ‘basic level’ buildings and is thus responsible for the school and class assignment within their school site. The basic level is another special feature of the city of Bern, which can be traced back to a cantonal pilot test from 2004 to 2010. In the so-called basic level classes, the kindergarten years and the first two primary school years are taught together in mixed-age classes. In contrast to the optimized year 2000, school assignment in the case of the now widespread basic level schools is now already decided with the assignment at the child’s age of four.

Regarding the length and nature of age-appropriate routes to school, in the canton of Bern it is up to the municipality to assess the reasonableness of a route to school on a case-by-case basis, and the decision may be appealed by the competent school inspectorate (Kanton Bern 1992, Art. 72). In a cantonal leaflet, the following aspects are listed, which are to be included in the assessment: The length and nature of the route to school, the difference in altitude, the age of the pupil, the presence of other pupils, possible dangers and the condition of the road or path (Bildungs- und Kulturdirektion Kanton Bern 2019). The traffic instructors of the cantonal police can be consulted for the assessment. In the same leaflet, there is a note that meters of altitude multiplied by 10 is included in the length of the route to school. In kindergarten, 1.5 km is considered reasonable, for primary school pupils of the 1st-3rd grade approx. 2 km, with intermediate steps up to 10 km for secondary school if the use of a bicycle is deemed reasonable.

Practice of school assignment in the school districts of Bern

Information about the assignment criteria for school enrollment can be found on the registration form of the municipal school administration for kindergarten or for the basic level. The form asks about the child's place of birth, nationality, hometown, the language spoken by the child (and the parents), and the child's knowledge of German (good, sufficient, poor, none). The questionnaire also asks about the preschool programs attended, as well as the external care used in addition to kindergarten (daycare center, after-school daycare, daycare parents), the
location and the times of use of the external care. Finally, the survey also asks about siblings and their years of birth.

In the case of the school district Breitenrain - Lorraine, the local school commission has specified the procedure and criteria for the assignment in a leaflet (Schulkreis Breitenrain - Lorraine 2019). It is stipulated that the school site principal coordinates the assignment and proceeds according to criteria and guidelines established jointly with the school commission (supervisory authority). Accordingly, an initial, rough assignment of the children takes place according to the small district allocation of the city of Bern. The individual assignment - especially of children living in border areas between the school sites - will be re-evaluated by the school site principals for each school year. The following criteria are used for this purpose:

- Residence and way to school
- Class balance: class size, distribution of grades, distribution of girls and boys, distribution of children with special needs / increased support needs, as well as the social mix
- Formation of groups (at least two children from the same class)
- For children of the kindergarten or the basic level, who are cared for during a major part of the school week in a daycare center or with daycare parents, this address applies for the assignment
- Reasoned requests

According to the principal Rita Holzer (site Spitalacker/Breitenrain in the corresponding school district), the distribution of age groups refers to the mixed-age classes, for example in the basic level, where the four cohorts should be approximately balanced. Regarding special needs, the language could also be considered, should there be many children who do not speak German at all. Principal Holzer finds it difficult to take social mix into account, because the applications do not show the social status of a foreigner, for example. Neither occupations nor housing situation are asked for. Only in the case of new buildings is it possible to estimate whether the apartments are expensive or not.

According to principal Holzer, the location of the daycare center attended is one of the most important criteria for assignment. She also tries to consider daycare center visits with a small percentage, so that daycare centers can accompany the children well in the first two years in kindergarten or in the basic level and parents do not "fall into a hole" during this time. Accordingly, the school site principals have an agreement with each daycare center regarding drop-off and pick-up from school and these could not be adjusted annually, since in each case the already assigned year would also be affected. After the two years in kindergarten or in the basic level, the child loses the right to attend a daycare center. There are no reassignments in the basic level classes; at most, new children are assigned to the classes according to the criteria. This ensures the consistency of the basic level class as an important element of this model. In the model of kindergarten and lower school classes, it is possible to influence the composition of classes by assigning the children of a kindergarten class who are transferring to the first class to two or three different lower school classes.

After a school has switched to the basic level model, the classes are "filled up" with the new year group. Regarding approvals, it is then a matter of the municipal school administration approving the opening of new classes, for example, and the canton approving class sizes. Shifts in the catchment areas are also always connected with the number of classes and the class size, and there it is currently an uphill battle due to the cost-cutting measures, so "we keep all our children together" (own translation). For example, she has had to turn down reassignment requests to prevent the closing of a basic level class resulting from not reaching the required number of children per class. Or existing classes must be merged into larger classes, but the room sizes are designed for 24 children. Accordingly, the number and size of classes is a heavily weighted criterion, and there is currently less openness when it comes to redistricting between school sites.

According to principal Holzer, boundary shifts between school sites are also made more difficult because in the system of mixed-age classes (also in the cycles following the basic level), the entire system collapses when a class is removed. If, for example, there are too few children in the area of the Lorraine-Wylergut site, then a border shift
in the direction of Breitfeld-Wankdorf is only possible because there is a large increase in new buildings there. The background to it is thus purely numerical.

Otherwise, it is also the case that not only is the school district quite self-contained due to natural and settlement conditions, but Lorraine-Wylergut and Spitalacker-Breitenrain, for example, are separated from each other by the Nordring road, because one does not want to lead children of this age over such busy roads. In contrast, there is some leeway regarding the Breitfeld-Wankdorf school site, whereby a so-called "review area" can be identified, in which assignments are made to one or the other school site based on reasonable school routes. But also within her school site it is the case that the balancing possibilities between the smaller school Breitenrain and the large school Spitalacker via the Moser street are limited, because this is considered to be rather dangerous and parents file complaints. There, it is currently being examined with the traffic instructor to install more speed 30 signs as well as a pedestrian crossing. However, at the time of writing, Moserstrasse was particularly dangerous due to a reconstruction, which is why assignments across Moser street were then avoided.

In general, a distinction must be made between the assignment to the school sites on the one hand and to the school buildings within the school site on the other hand. For the latter case only the respective school site principal is responsible. The interviewed principal Holzer is at the same time deputy managing principal for the entire school district and she manages the portfolio of school assignments. The coordination of allocations between school sites is a constant agenda item at the meetings of the school principals of the school district, requests of individual pupils are weighted according to the agreed criteria and finally they decide - usually unanimously. The reasons are noted in the minutes and recorded in a special list. This list includes all children who do not attend the school site according to their home address, so that an overview can be ensured. The Scolaris software is used as the school management system, containing the addresses of the pupils and the assigned school sites.

Once the assignment to schools has taken place, a so-called "round of boards" follows for the formation of classes within the school site of principal Holzer. There she allocates the newly entering pupils to the classes and in a second step discusses the class assignments together with the teachers. In this step, the feedback from the teachers is being considered, although factual reasons count first and foremost.

Practice of school space planning of the city of Bern

In the city of Bern, the city school administration is in charge of school space planning, with the city's construction departments (real estate, structural engineering), statistical services, city planning and the school site principals participating in the school space planning coordination committee. According to the deputy head of the school administration, Jörg Moor, the school administrations' task is to identify school space requirements based on pupil forecasts and to initiate orders for additional school space. In addition to new buildings, this includes modular buildings, supplementary buildings, space optimization or leasing in private properties. Moor would wish that more social aspects could be taken into account in school space planning, but he said that people in Bern are also happy if new school space can be created anywhere at all. In a densely populated city with little free space and with pressure from various sides, the hard facts such as the reasonable distances to school must be considered. But the school principals would also have a say in this coordination committee and their know-how from their neighborhoods should be better integrated in the future.

In concrete terms, the necessary school space areas are first determined, this then goes to Immobilien Stadt Bern and there to portfolio management, whereupon a strategy is drawn up. For example, feasibility studies are carried out, whereby sensible locations are evaluated together with planning law aspects. For example, it is easy to zone an area for infrastructure and build a large school in the new Vierfeld district. It is more difficult in other cases, however, where a school building must be inserted into a park-like landscape with school routes over railroad lines, due to a lack of alternatives. Although numerous participation procedures were carried out with the residents, social aspects could not be included because no alternative location is possible. According to the deputy head of the school district, school space planning is further complicated by the fact that most of the school buildings in Bern are listed buildings. Where, for example, loft conversions or building extensions are being considered, they often fail because of the building regulations or the framework conditions for the protection of historical
monuments. The Matte school building, for example, is located in the UNESCO perimeter of Bern's old town. These difficulties are also known to the Bernese municipal council (executive). In connection with a new school space strategy, a flexible approach to the framework conditions must be examined to be able to cover the school space requirements.

Challenges in mixing schools in the city of Bern

When asked whether it is possible to work towards a social mix when allocating schools, principal Holzer says that she tries to take this into account when allocating schools, so that there are not only foreign-language children in one place - provided that this is not already predetermined by the daycare locations attended. In the case of the already existing all-day school, a voluntary offer in which parents from the school district can register their children, there are eight foreign speakers in two classes, in the case of the other 16 classes there are 23 foreign speakers, which then amounts to one to four foreign speakers per class. If, in addition to the daycare centers attended, the wishes of the parents are also considered due to the organization or due to friendships, then it could be that in one year group two foreign speakers come into the same class, which then means a greater diversity for the corresponding basic level classes. Otherwise, the family background is considered when there is an application for assignment, but mostly it is care problems that play a role in these applications. It should be noted that their school site has a very low percentage of foreigners. There are schools in the western part of the city, for example, that have a foreign language percentage of almost 100 percent in their classes.

In response to the question of whether the choice of daycare center is also made strategically by parents to be assigned to the desired school, principal Holzer says that she sometimes calls this "the only school choice" available in the city of Bern. Mostly, however, the parents are simply looking for solutions to organize the pick-up and drop-off. In fact, there are also families who move to be able to stay with them at the school site.

According to principal Holzer, it is the case in her school site that families are very open to accepting refugee children in the school, for example, which was demonstrated when a temporary transit center for refugees was set up in the old fire department. It is important to note that their school site is placed relatively low on the social index, while the index for Wankdorf is somewhat higher, although not as high as in the west of Bern.

The interviewed deputy head of the Bernese school administration, Jörg Moor, finds the endeavor for a stronger social and cultural mix a good thing. Due to the great differences between, for example, the heavily burdened school districts of Bethlehem and Bünglitz on the one hand and the academic district of Länggasse or the ambassador district in Kirchenfeld on the other, the existing principle of district schools should actually be abandoned and a city-wide distribution according to social background should be envisaged and, if necessary, school transports should also be considered - a project that was examined about twenty years ago. However, the request failed "grandiosely" at that time. According to the deputy head of the school administration, resistance against the mixing or against the abandonment of the principle of neighborhood schools through longer school transports is to be expected. The parents of the Kirchenfeld school, for example, have strongly opposed a transport of pupils to another part of town, which would have been necessary during the reconstruction phase of their school building. On the part of the school principals, moreover, the school district boundaries are regarded as fixed, as is currently evident in questions concerning the formation of school district-spanning upper school centers. This is despite the current school space strategy adopted by the municipal council, which explicitly formulates such a procedure to secure school space (chap. 2.2, para. 3). Regarding the upper school centers, there are fears of ghettoization and anonymization due to their size. Similar resistance could also be expected at the level of school assignment in the lower school.
Possible requirements for an optimization tool for school catchment areas in the city of Bern

When asked how she sees the advantages and problems of using the assignment procedure developed here to support school assignment, Principal Holzer says that in her school site, the optimized catchment areas would not work because of the many daycare centers. If suddenly another criterion determines the assignment, then this could burst the school buildings. She thinks the tool is good to be able to react to possible developments. She thinks it would be good, for example, to take foreign languages into account as a basis for school assignment. But it could be that everything falls apart, especially in relation to the daycare centers.

When asked, the deputy head of the Bern school district, Jörg Moor, points out that there is an above-average proportion of daycare centers in Spitalacker, which means that the scope for assignments in this school site is more limited than in other school sites. In addition, the municipal agreements with the daycare centers would already include the accompaniment to two kindergarten locations. It should be added that Bern also has a comprehensive school-based day structure offering. Parents have a legal right to day care for their children in a day school from kindergarten age.

If it is possible, with the help of the data-based procedure, to work towards an equalization of the social burden through marginal changes to the catchment area boundaries alone, then the deputy head of the school district believes that the procedure has a chance for implementation in the city of Bern. In contrast to earlier initiatives, which envisaged a large-scale redistribution, the procedure fits in with current practice, according to which site principals can carry out such a redistribution within their competencies. In addition to the current equalization of class size, the social component would then also be considered to a greater extent.

Preliminary conclusions

Regarding the practice of school assignment and school space planning, differences but also similarities can be identified. Due to the cantonal regulations, the responsibility for school assignment in Zurich and Winterthur lies with the district school authority as the supervisory body, whereas in Bern, allocation between the school sites (school building groups) within the school districts is coordinated by the site school administrators.

Although the canton of Zurich prescribes balanced compositions in terms of social and linguistic background as well as in terms of ability for school assignment, in addition to school routes and class sizes, the one-sided interpretation of this specification on class formation is striking in the city of Zurich, where a web application for recording individual competencies and needs is also intended for class formation only. Instead, the school authorities in the city of Winterthur focus mainly on the sensible distribution of children with special needs, especially integrated special education pupils, among the various schools and classes. In the case of the city of Bern, the city has set itself the target of school assignment for social mixing, although no data on the individual pupils are available for the social aspect of all things. At least in the examined school district Breitenrain-Lorraine, the social mix appears to be a subordinate aspect, while foreign language skills are at best subsumed under special needs.

Regarding school space planning, it is evident in all three cities that aspects of social mix are not currently taken into account, with reference being made to the limited available space, the need for short school routes in the neighborhood, or the protection of historical monuments.

The resistance of parents, but also in part of the school district authorities and school principals, to giving up the existing catchment areas and neighborhood references, including fears of more mixed schools, proves to be a challenge for social mixing. In addition, the interviewed school site principal in Bern in particular asserts constraints due to the mixed-age classes and the consideration of the attended daycare location. From the point of view of the authors of the study, however, the peculiarities in Bern do not speak against a data-based assignment, since the assignment proposals can be applied to the free places in existing school classes and because, with the appropriate political will, it would also be possible to reassign daycare locations to the school sites.
Despite possible reservations, interviewees in all cities can be identified who see a potential in a data-based school assignment to support the existing school assignment, not least because it can be integrated into the existing assignment processes and because, with the small-scale adjustments to the catchment area boundaries, it starts at a level where implementations would in principle also be politically feasible.
Conclusions and recommendations

The aim of this study was to examine the role of school policy in ensuring mixing between urban schools against the background of segregated residential neighborhoods in Swiss cities. In addition, possibilities for increasing mixing between schools should be identified. The relevance of these research objectives stems from the established findings that the social and ethnic composition of schools has a significant impact on individual school performance - in addition to the background of individual pupils. Nowhere is the so-called composition effect at the school level more pronounced than in Switzerland (s. Figure 86 in the Appendix; OECD 2016). Our own analyses confirm once again that in Switzerland the same child has different chances of success at school and in further personal and professional development depending on the composition of the school attended. In this respect, the mixing of schools is a central prerequisite for institutionally ensuring equal opportunities.

Specifically, we investigated the importance of the assignment procedure used in Switzerland and elsewhere, whereby the responsible school authority determines school catchment areas, assigning children to a school according to their place of residence. Using the cities of Basel, Bern, Geneva, Lausanne, Winterthur and Zurich as examples, the following questions were investigated: Module 1) Is the effect of residential segregation on the composition of schools enhanced or diminished by the defined catchment areas? Module 2) Do the school authorities have sufficient leeway at all to bring about greater mixing between schools through the determination of catchment areas? Module 3) How does the algorithm proposed here for small-scale optimization of catchment areas square with existing regulations and with practice in school assignment? This chapter first summarizes the main findings of the study. Based on this, we derive a few specific recommendations.

Main findings of the study

The extent to which the social and ethnic composition of schools affects school performance ('composition effect') in Switzerland is shown not only by previous international and national research, but also by the analyses conducted specifically on the reading performance of secondary school students (PISA 2000) and on the German language performance of 3rd primary school pupils in the canton of Zurich (Zürcher Lernstandserhebung 2006). We confirm earlier findings, according to which:

- a low to middle social mix in schools is not associated with a significant drop in performance, but this only sets in at a proportion of around 30 to 40 percent of pupils from socially disadvantaged and foreign-language families ('tipping effect').

This finding is of high political relevance. It means that mixing schools creates more equal opportunities for children and young people from particularly stressed neighborhoods without compromising the performance of other children and young people.

Analogous to school performance, the typical educational paths also differ depending on the composition of the schools, which can be impressively shown by evaluating the transfer rates in the school districts of the cities studied. The ranges in terms of transfer to the lower-level secondary school types according to neighborhood or school district are particularly pronounced in Basel, Bern and Zurich. No spatial data on transfer rates were provided for Geneva. In Lausanne and Winterthur, the differences between the school districts are less pronounced, although the differences between neighborhoods are underestimated due to the socio-spatial differences within the school districts (see chapter unequal access to education).

These spatial divergences initially reflect the different individual backgrounds of the children (educational level of parents, linguistic-cultural barriers), but are amplified by compositional effects at the school level. A child in a school with a high concentration of children from educationally disadvantaged and poorly integrated families has
been shown to have more difficult access to more demanding types of schools at secondary level than if the same child attended a school with a more favorable composition in a different neighborhood. Despite processes of upgrading and a “new” influx of educationally advantaged population strata, the differences between school districts have remained large over the past two decades, both in the city of Zurich and in the other cities studied.

Module 1: Relationship between residential and school segregation.

Both social and ethnic segregation between neighborhoods and segregation between schools are increasing due to migration, especially in cities, according to findings from recent European studies. Despite the introduction of elements of free school choice in some countries and despite the increasing influx of private schools, the growing segregation between schools even in these countries is mainly attributed to increasing residential segregation. In countries such as Switzerland, the determination of school catchment areas is the key mechanism for how residential segregation also affects segregation between schools. Based on 2000 census data for lower school pupils, this study captures segregation by linguistic and socioeconomic background through a concentration index. This measures the concentration of pupils from disadvantaged backgrounds within schools and their immediate neighborhoods. To do this, the school catchment areas of the cities studied first had to be reconstructed for the 2000/2001 school year. According to the catchment areas valid in 2000, the range of the proportions of disadvantaged pupils between the schools was highest in Zurich (5 to 73 percent), followed by the cities of Basel, Bern and Lausanne with values up to 60 percent. Finally, in Geneva and Winterthur, the maximum values were somewhat lower, at 50 and 40 percent, respectively.

Evidence that school authorities strategically set catchment boundaries to increase segregation between schools beyond citywide residential segregation could not be identified. Instead, it can be shown that in all cities the composition of schools in the lower grades largely reflects the composition of the schools’ immediate neighborhoods. An exception is Geneva, where catchment areas create a certain leveling between neighborhoods, but this leveling is limited to schools with medium and low concentration values. Accordingly, it can be stated that in the 2000/01 school year, no efforts can be identified to counteract the pronounced segregation of more stressed residential neighborhoods by defining the school catchment areas.

In summary, regarding the relationship between segregated neighborhoods and the composition of schools for all cities, it can be stated that:

- in the cities studied, the composition of schools by linguistic and socioeconomic origin largely reflects the composition of the schools’ immediate neighborhoods or residential segregation is even exacerbated in certain school districts. The effect of segregation, especially in disadvantaged neighborhoods, is generally not reinforced by the specific layout of the catchment areas, but neither is it mitigated.
- there are considerable differences in the composition of schools by language and socioeconomic background.

Module 2: Room for maneuver for greater mixing

To exhibit the room for maneuver that is available to school authorities to work towards a greater mix between schools despite segregated residential neighborhoods, we developed a novel, detailed algorithm for the small-scale optimization of school catchment areas as part of the present study. The goal is not to allocate individual pupils, but to develop proposals for adjusting catchment areas along their boundaries. The algorithm aims to bring the concentration index of all schools as close as possible to the citywide average. As boundary conditions, the maximum school route lengths and the available capacities of the schools are considered. For this purpose, the individual school routes are simulated for all optimization steps based on a comprehensive network of footpaths, whereby heavily trafficked roads as well as difficult road crossings are avoided. The optimized catchment area maps and the resulting school concentration values to the studied cities suggest that:
Conclusions and recommendations

• small-scale adjustments to the catchment area boundaries can create a considerable balance between the schools, whereby a mixing of the most burdened schools can succeed even if the existing school capacities and maximum school route lengths are adhered to.

• an extended leeway regarding school capacities and maximum school route lengths, if necessary combined with more permeable catchment areas, can further increase the mix depending on the city studied.

• the equalization through small-scale adjustments is significantly greater within school districts than across the city.

• the location of existing schools, as well as their accessibility, strongly influence local optimization possibilities.

• disproportionate concentrations in individual schools (in relation to the surrounding ‘neighborhood’) can, with a few exceptions, be explained by their isolated location (highways, railroad tracks).

• a stronger leveling between the school districts requires a detachment of school space planning from the school district boundaries as well as a selective flexibilization of the maximum school route length.

Although the more current available data (2010 to 2018 structural survey, pooled samples only) do not allow for fresher optimization analyses, preliminary analyses of school-based neighborhoods in the 2019/20 school year indicate that the schools and neighborhoods with the highest concentration indices have geographically shifted from the 2000/01 school year in several cities. At the same time, the results suggest that the segregation between residential neighborhoods is still reproduced one-to-one in the allocation of school catchment areas today. In detail, it can be stated that:

• upgrading processes have resulted in several schools with previously highest concentrations now ranking in the middle. This shifts the focus to the neighborhoods that continue to be burdened complemented with individual neighborhoods of rising concern.

• the segregation patterns around these neighborhoods today still indicate considerable potential for mixing among the schools in question.

• catchment areas in force today are most likely to reproduce social and ethnic residential segregation one-to-one even today.

• new school building locations have contributed little to mixing, depending on the location chosen.

Module 3: School assignment and school space planning in practice

The experts from Bern, Winterthur and Zurich interviewed in Module 3 reaffirm the importance of anchoring schools in the neighborhoods, relying on mixed classes within schools and on motivated local school teams (school principal, teaching staff, school social work) to give children in schools with a high concentration index "the chance they deserve". For greater mixing between schools, they see a central role for urban development policy and housing subsidies. In principle, the idea of the proposed auxiliary tool meets with the interest of several respondents. The algorithm could easily be integrated into existing pupil management databases, leaving school allocators in district school boards with the task of reviewing the proposed catchment areas and making final individual assignments. At the same time, the concerns initially raised point to potential misunderstandings about the auxiliary tool proposed here. The following features of the tool should be reemphasized here:

• This is about small-scale adjustments to catchment areas, largely within school districts: no school buses are required.

• Individual pupils or families are not selected and moved between schools; rather, street blocks along area boundaries are reassigned and areas remain contiguous (still "neighborhood schools" but with good mixing).
If optimized catchment areas for 1st grade are also considered in the assignment to kindergartens, pupils can remain in the same ‘school unit’ from kindergarten to 6th grade as before.

In principle, the data-based assignment procedure can be adapted to the requirements of the respective school system (e.g., basic level of the city of Bern, consideration of the location of extra-familial care when assigning to kindergarten/basic level).

The optimization is based on a scientifically justified index, the algorithm and the parameters considered are transparently documented.

Within school districts or even between school districts, balancing is possible without necessarily assuming additional capacity or longer school routes.

Balancing between schools also means that reassigning a street block no longer seems so dramatic, and the mixing of schools may also contribute to a more balanced development of residential neighborhoods further ahead.

**Recommendations**

Schools with high concentrations of children from educationally disadvantaged families or families with little familiarity with the school system face significant challenges in teaching basic skills and providing fair access to more demanding types of schools at secondary level. At the same time, schools with predominantly children from educationally advantaged and well-integrated families would also benefit from greater mixing. Learning to deal with diversity at an early age not only strengthens social skills, critical thinking, creativity and problem-solving abilities. It is also in demand in the internationally highly networked labor market and strengthens social cohesion across neighborhood boundaries and social and cultural divides. While these positive aspects of mixed schools are still completely unexplored in Switzerland, comprehensive evidence has existed for almost seven decades in the USA (for an overview article see Siegel-Hawley 2012). The results of the study suggest that the social integration potential attributed to the early stages of public schooling is still little exploited in the cities studied. Segregation by place of residence is reproduced almost one-to-one with the catchment areas in force today, while the data-based analysis for the 2000/01 school year reveals scope for action to achieve greater mixing.

Specifically, this study formulates the following recommendations:

- The aspect of mixing according to social and linguistic background or by performance should not only be considered when assigning to classes within the schools, but already when determining the catchment areas, so that the highest possible mixing between schools is made possible.
- Social and ethnic mixing among schools should also be an important goal of school space planning. Opportunities for greater mixing should be considered in expansions as well as in the designation of new school building locations. To achieve greater mixing of schools in isolated locations, capacity shifts should be examined, as should structural and traffic planning measures to improve accessibility from other neighborhoods.
- Urban development policy and private and non-profit housing have a central role to play in achieving mixed neighborhoods and thus mixed schools. Even if upgraded neighborhoods go hand in hand with more mixed schools, at least initially, it should be ensured that, during renewal and densification, socially vulnerable families are not simply pushed into the remaining socially burdened neighborhoods or out of the city altogether.
- Targeted mixing in school assignment, as well as considerations of capacity shifts and new school building locations, should be facilitated by a data-driven analysis tool. The algorithm developed here could easily be integrated into existing assignment procedures without significantly changing the work of school allocators. For the social acceptance of adapted catchment areas, it is important to disclose how the algorithm works and
to transparently communicate the politically determined target values together with the indicators that are being used.
Schools with high concentrations of children from educationally disadvantaged families or families with little familiarity with the school system face significant challenges in teaching basic skills and providing fair access to more challenging types of schools. This is because children in these schools, in the cities studied and elsewhere, are at a double to triple disadvantage (Coradi Vellacott 2007): first, their family environments mostly do not provide the same possibilities for encouragement and support as do more educationally advantaged and well-integrated children. Second, the composition of these schools has been shown to adversely affect the academic performance of all children taught there, regardless of individual background. Third, such schools are often located in communities that are less well equipped than better-off communities within the same agglomeration.

It is therefore to be welcomed that the "Cities Initiative on Education" (section of the Swiss Association of Cities) calls for equal opportunities for all in its 2011 position paper on education policy:

"Switzerland is a country with highly developed industry and service sectors. As such, we cannot afford that educational success depends significantly on the language, origin and/or socio-economic background of the children. All pupils, regardless of their background, should be able to develop according to their abilities and skills. They should later take responsibility for themselves and for society."

(Städteinitiative Bildung 2011, own translation)

In a foundational educational policy paper, the Cities Initiative on Education states a minimal consensus on goals and attitudes toward fairness and inclusion (Städteinitiative Bildung 2016). In doing so, the paper does affirm the constitutional principle that all children and youth should be able to "educate, train, and further their education according to their abilities" (Federal Constitution, Art. 41). However, the Cities Initiative on Education seems to content itself with teaching all elementary school pupils the basic competencies or the minimum standards of the ‘Curriculum 21’ agreed by the German speaking cantons. Beyond that, it merely seeks to ensure that access to extended and postsecondary education is not impeded by financial barriers or other forms of discrimination. These are, of course, no small tasks (cp. Schweizerischer Wissenschaftsrat 2018). Nevertheless, it is noticeable how the foundational paper substantially lowers its own standards for achieving equal opportunities compared to the position paper of 2011 (cp. also Herzog 2019):

"For the Cities Initiative on Education, equity in elementary school does not mean neutralizing unequal educational outcomes (even though they may have arisen because of social disadvantage)."

(Städteinitiative Bildung 2016)

It is clear that the elementary school subsystem cannot eliminate all social injustices, especially when these injustices are outside its sphere of influence. Thus, in our study, it is understandable when representatives of school authorities point to the responsibility of urban planning and private and nonprofit housing developers to create mixed-income neighborhoods. And yet, also the foundational paper advocates affirmative action programs to compensate for socio-spatially disadvantaged schools. For example, the "QUIMS (Quality in Multicultural Schools)" program in the canton of Zurich is designed to promote the achievement level of all pupils in schools with a high percentage of foreign speakers (mixed index of over 40 percent) (Kanton Zürich 2005, §25). Through language support, promotion of school success and cooperation with parents, a "high level of performance, fair educational opportunities and the integration of all pupils" should also be ensured in these schools. (Bildungsdirektion Kanton Zürich 2008, 4, own translation). In the example of the canton of Zurich, the demand for educational equity goes much further than simply ensuring that "appropriate minimum academic standards” (cp. Städteinitiative Bildung 2016) can be taught at the schools in question can be taught at the schools in question.
Similar to QUIMS in the canton of Zurich, we could mention the REP program in Geneva or Equité in Lausanne (Roulet 2013a).

Not positive discrimination, but nevertheless the promotion of inclusion is the purpose of the transformation of all schools into day schools ("Tagesschule 2025") in the city of Zurich. This not only aims to improve the compatibility between work and family, but also to explicitly contribute to educational equity thanks to increased support and beneficial peer effects:

"The extended attendance time in the day school enables diverse encounters in different situations outside the classroom and thus experiences beyond school learning. The Day School 2025 brings pupils with different interests, cultures and abilities closer together. Low-threshold and voluntary offers are available to the children during lunchtime. In this way, Day Schools 2025 support the social integration and advancement of all pupils and contribute to educational equity."

(Stadt Zürich 2018, 3, own translation)

Equally important, however, is the second strand of measures recommended in the City Initiative on Education's foundational paper, regarding the prevention of discrimination in access to extended and postsecondary educational opportunities (Städteinitiative Bildung 2016). For example, school careers and success in finding an apprenticeship are largely determined by the educational status of parents, migration background, language and gender even before school entry. This social selectivity is particularly pronounced in highly stratified and segmented education systems, as is the case in Switzerland (Schweizerischer Wissenschaftsrat 2018). With the selection into different secondary school types and in some cantons even the Gymnasium already after 6 years of primary school, Switzerland is one of the countries with the most selective school systems. Additionally, the City Initiative on Education recommends measures in early education, teaching in mixed-ability schools, later selection decisions and permeability, as well as measures to raise awareness of the resources of migrants (Städteinitiative Bildung 2016). Additional measures would include free exam preparation courses for the Gymnasium or projects that support those children and adolescents in the transitions who lack a supportive environment (in the canton of Zurich, this would be "ChagALL" at the Gymnasium Unterstrass, "Future Kids" from the AOZ, children support by Arche, etc.).

The present study proposes an additional element for an urban school policy that can complement the aforementioned measures to improve equity: school mixing. Although it is clear that school performance is primarily shaped by individual background, and only secondarily by class or school composition, the impairments in segregated schools are considerable (compare sub-section on composition effects in Switzerland and Figure 86 in the Appendix; OECD 2016; Erzinger, Jäger-Biela, and Hauser 2019; Moser et al. 2011). It is no coincidence that the Zurich QUIMS program allocates resources according to school composition ("Mixed index" above 40 percent). However, the program is not sufficient to actually compensate for disadvantage based on composition (Maag Merki et al. 2012; for same results for 'REP' in Geneva see Soussi and Nidegger 2010). If learning conditions are demonstrably dependent on the composition of the school, wouldn't it be obvious to pay attention to the best possible social and ethnic mix when defining school catchment areas and also in school space planning?

The algorithm developed during this study makes it possible, based on small-scale adjustments, to reduce schools with high concentration indices (medium share of foreign speakers and those with a low educational level, not to be confused with the QUIMS mixed index) in the 2000/01 school year (cf. section on analysis at school district level in the chapter on Module 2). These are significant changes in these cases. At the same time, the algorithm ensured that the optimized catchment areas do not lead to an excessive burden for the surrounding schools either (cf. chapter data and methods).

This is not to deny, however, that in the 2000/01 school year the concentration of burdened schools in certain school districts (Limmattal in Zurich, northern Kleinbasel, Bethlehem in Bern) made it impossible to lower the concentration values for most schools. While upgrading (and displacement) processes have dissolved or at least
broken up such agglomerations in many places today, a stronger mixing of individual schools in isolated locations is likely to remain difficult today. In this respect, even more efforts should be made in such cases to achieve greater mixing through appropriate school space planning, through structural measures (school routes) and more generally through urban development and urban housing policies.

Even in more mixed schools, the heterogeneous composition requires additional support measures, which can be implemented in the canton of Zurich as part of the QUIMS program, in the canton of Geneva as part of REP, and in the canton of Vaud with the Egalité program.

Conversely, schools with predominantly children from more educationally advantaged and well-integrated families would also benefit from greater mixing. As long as the schools have moderate concentration indices, the performance of the pupils would not be further affected. On the contrary, greater mixing has a beneficial effect on their personal development. Learning to deal with diversity at an early age is also in demand in the internationally highly networked labor market and strengthens social cohesion across neighborhood boundaries as well as social and cultural divides. Social and ethnic diversity has long been a reality in urban areas in Switzerland, and the urban area benefits economically and culturally from this diversity. This urban area also calls for a mixed public school.

In addition to programs for socially disadvantaged schools, the introduction of day schools and considerations of the social selectivity of the school system, school mixing offers a practicable and desirable measure on the way to more equal opportunities in the Swiss public school.


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Appendix

Compositional effects at the school level in OECD countries with a higher proportion of students with a migration background (PISA 2015)

Score-point difference in science between students attending schools with low and high concentrations of immigrant students

1. ESCS refers to the PISA index of economic, social and cultural status.

Note: Only countries in which the percentage of immigrant students is above 6.25% and with available index of economic, social and cultural status (ESCS) data are shown. Statistically significant score-point differences are marked by a darker tone. The thresholds for defining schools with low and high immigrant concentrations are country-specific and shown next to country names. The threshold is the percentage of immigrant students in the school that divides the 50% of the students attending schools with the smallest percentage of immigrants, and the 50% of the students attending schools with the largest percentage of immigrants, within each country/economy.

Interpretation for Switzerland: On a point scale with a mean of 500 and a standard deviation of 100 for all countries, students in Switzerland achieve a mean of 506 in science (not reported in the figure). In Switzerland, schools with an above-average proportion of migrants (>28%) score 54 points lower on this scale than schools with a below-average proportion of migrants. If the ESCS and the migration status of the students as well as the average ESCS of the school are considered in the comparison, then the composition still has a significant effect with a difference of 19 points. We speak of an effect size of 54% and 19%, respectively.

Source: OECD (2016), Figure I.7.12.
### Composition effects at the school level in Switzerland for communities with more than 15,000 inhabitants (PISA 2000)

<table>
<thead>
<tr>
<th>Dependent variable: <strong>reading performance</strong></th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>535.31***</td>
</tr>
<tr>
<td></td>
<td>(23.93)</td>
</tr>
<tr>
<td><strong>LEVEL 1: PUPIL</strong></td>
<td></td>
</tr>
<tr>
<td>Social background: Highest index value of the parental occupations (HISEI, z-transformed)</td>
<td>11.54***</td>
</tr>
<tr>
<td></td>
<td>(3.49)</td>
</tr>
<tr>
<td>Migration background</td>
<td>-34.11***</td>
</tr>
<tr>
<td></td>
<td>(8.19)</td>
</tr>
<tr>
<td>Foreign language (main language)</td>
<td>-22.51*</td>
</tr>
<tr>
<td></td>
<td>(9.32)</td>
</tr>
<tr>
<td>Gender (female)</td>
<td>16.00*</td>
</tr>
<tr>
<td></td>
<td>(6.24)</td>
</tr>
<tr>
<td><strong>LEVEL 2: SCHOOL</strong></td>
<td></td>
</tr>
<tr>
<td>Concentration index (reference: 1st quartile, between 0% and 17%)</td>
<td></td>
</tr>
<tr>
<td>- 2nd quartile (between 17% and 22%)</td>
<td>-14.08</td>
</tr>
<tr>
<td></td>
<td>(13.25)</td>
</tr>
<tr>
<td>- 3rd quartile (between 22% and 32%)</td>
<td>4.12</td>
</tr>
<tr>
<td></td>
<td>(12.63)</td>
</tr>
<tr>
<td>- 4th quartile (between 32% and 58%)</td>
<td>-49.24**</td>
</tr>
<tr>
<td></td>
<td>(16.43)</td>
</tr>
</tbody>
</table>

Residual variance: School level 96.37
Residual variance: Pupil level 4803.70
Number of observations (pupils) 572
Number of clusters (schools) 39

Remarks: Standard errors in parentheses. *** p < 0.001, ** p < 0.01, * p < 0.05
Fixed effects for cantons per language region and school type (exclusion: Gymnasium).
Source: Own analysis based on PISA 2000 (incl. additional national sample, exclusion of Gymnasium students) using the BIFIEsurvey package in the statistics program R.
Composition effects at the class level in the canton of Zurich (Zurich Learning Survey 2006)

<table>
<thead>
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<th>Dependent variable: German performance</th>
<th>Model</th>
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</thead>
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<tr>
<td>Constant</td>
<td>504.72*** (11.76)</td>
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<td>LEVEL 1: PUPIL</td>
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<tr>
<td>Socioeconomic status (z-S)</td>
<td>25.87*** (3.10)</td>
</tr>
<tr>
<td>Migration background</td>
<td>-2.91 (6.46)</td>
</tr>
<tr>
<td>Foreign language (first language)</td>
<td>-26.78*** (7.39)</td>
</tr>
<tr>
<td>Gender (female)</td>
<td>38.65*** (4.84)</td>
</tr>
<tr>
<td>LEVEL 2: CLASS</td>
<td></td>
</tr>
<tr>
<td>Concentration index (reference: 1st quartile, between 0% and 14%)</td>
<td></td>
</tr>
<tr>
<td>- 2nd quartile (between 14% and 26%)</td>
<td>-11.62 (12.39)</td>
</tr>
<tr>
<td>- 3rd quartile (between 26% and 40%)</td>
<td>-14.07 (12.18)</td>
</tr>
<tr>
<td>- 4th quartile (between 40% and 70%)</td>
<td>-34.81** (12.49)</td>
</tr>
<tr>
<td>Participation in the project &quot;Partially autonomous elementary school&quot; (TaV)</td>
<td>-1.60 (9.59)</td>
</tr>
<tr>
<td>Participation in &quot;Quality in multicultural schools&quot; program (QUIMS.)</td>
<td>27.93 (17.78)</td>
</tr>
<tr>
<td>Residual variance: Level class</td>
<td>1016.28</td>
</tr>
<tr>
<td>Residual variance: Pupil level</td>
<td>6345.16</td>
</tr>
<tr>
<td>Number of observations (pupils)</td>
<td>1186</td>
</tr>
<tr>
<td>Number of clusters (schools)</td>
<td>94</td>
</tr>
</tbody>
</table>

Remarks: Standard errors in parentheses. *** p < 0.001, ** p < 0.01, * p < 0.05
Source: Own analysis based on Zurich Learning Survey 2006 using the BIFIEsurvey package in the statistics program R.

Data availability

The pilot study (Dlabac and Amrhein 2019) was originally designed to examine current catchment areas provided by the school board using pooled structural data from 2010 to 2015. However, because the structural survey samples do not provide reliable information on the characteristics of lower school pupils in small-scale street blocks, we depended on a full survey to model alternative catchment areas. This purpose could have been served by the school-internal pupil administration database, which does not contain any information on the socioeconomic background of the children, but does contain data on first language, a rough evaluation of individual German language skills, and performance according to the kindergarten teacher. In contrast to the request for the current catchment areas and for conducting interviews with representatives of the school authorities, the follow-up request for anonymized data from the pupil management database was not approved by the Conference of Presidents of the City of Zurich School Board at this time. However, following the publication of the pilot study (Dlabac and Amrhein 2019), two selected school district authorities in the city of Zurich expressed their support for an in-depth study with anonymized data from the pupil administrative database. After in-depth data protection clarifications,
the data from the pupil administration database could be obtained at the beginning of 2021 and evaluated in the context of an in-depth study (not part of the present study). Furthermore, current data from the education statistics of the Canton of Zurich (BISTA) were not considered for the pilot study, as they do not allow for an exact spatial location of the pupils without further ado. In addition, these statistics do not include the educational background of the parents, nor do they contain information on academic performance or support needs for the lower school. Therefore, for a reliable analysis of school segregation as well as for the small-scale optimization of catchment areas, only geocoded personal data from the 2000 census (full census) were available. This data set, with its diverse characteristics, thus forms the basis for the evaluations for the school year 2000/2001 for the pilot study in the city of Zurich, but also for all other cities examined in this follow-up study. Parents and their school-age children were considered, provided they attended the public school in the respective city. For children who had both a civil and an economic place of residence, the one within the respective city was considered. If both places of residence were within the respective city, the one that was closer to the specified school was taken. In addition to compulsory schooling, the meter coordinates to the place of residence and the school attended, information on the child's foreign language (first language) and the parents' educational level (highest completed formal education) were of central importance. Since the census does not provide any information on the school year attended by the children, it was also necessary to refer to the dates of birth and the cutoff date for school enrollment in order to determine the school year (cf. following section). From the information on the coordinates of the school attended, as well as in some cases additional information on pupil numbers and schools for the year 2000 from the cantonal statistics (cf. Table 1), it was possible to determine the locations and actual capacities of the lower schools in the year 2000.

<table>
<thead>
<tr>
<th>City</th>
<th>Additional data 2000</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basel</td>
<td>Data on pupil numbers and schools as of 2000 (data per school and total pupil numbers 1st-3rd grade).</td>
<td>Basel City Statistical Office</td>
</tr>
<tr>
<td>Bern</td>
<td>Data on pupil numbers and schools as of 2000 (data per school and grade level).</td>
<td>Bern School Administration, Arsis Informatik</td>
</tr>
<tr>
<td>Geneva</td>
<td>Data on pupil numbers and schools as of 2000 (data per school and grade level).</td>
<td>Education statistics of the Canton of Geneva; Service de la recherche en éducation (SRED)</td>
</tr>
<tr>
<td>Lausanne</td>
<td>Information on pupil numbers (individual records) and schools as of the year 2000</td>
<td>Education statistics of the canton of Vaud; Unité de recherche pour le pilotage des systèmes pédagogiques (URSP)</td>
</tr>
<tr>
<td>Winterthur</td>
<td>Data on pupil numbers and schools as of 2000 (data per school, type of education, and grade level).</td>
<td>Education statistics of the Canton of Zurich</td>
</tr>
<tr>
<td>Zurich</td>
<td>Data on pupil numbers and schools as of 2000 (data per school, type of education, and grade level).</td>
<td>Education statistics of the Canton of Zurich</td>
</tr>
</tbody>
</table>

Table 1: Data used for the reconstruction of school locations and their capacities in addition to the data from the 2000 census.

In contrast to the geodata of the current catchment areas of the schools (2019/20) for the city of Zurich, the follow-up request for the release of the catchment areas in the 2000/01 school year was also rejected at the time the pilot study was conducted. The catchment areas for the 2000/01 school year were also not published by the other cities studied or were not available in digital form at all. Therefore, the study is based on reconstructed catchment areas based on the information on the school attended in the 2000 census. A detailed description of the method for the reconstruction is also provided in the corresponding section in the appendix.
For the preliminary analyses for the 2019/20 school year, different data sources were available in addition to the spatial decomposition into 'school neighborhoods' for the cities studied. The latter are summarized in Table 2. Figures on the concentration indices for the school 'neighborhoods' were omitted to prevent direct conclusions on the current burden on specific schools and to avoid further promoting segregative behavior in residential choice. However, aggregate evaluations based on the various data sources were made and mapped (see respective chapter on Preliminary Analyses of 2019/20 'School Neighborhoods'). The respective chapter also describes whether the evaluations are based on structural survey data.

<table>
<thead>
<tr>
<th>City</th>
<th>Data on current catchment areas16</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basel</td>
<td>No catchment areas and no reconstruction, but use of individual records on pupils in 1st - 3rd grade (primary level) and school attended.</td>
<td>Basel City Statistical Office</td>
</tr>
<tr>
<td>Bern</td>
<td>No catchment areas and no reconstruction, as these are subject to strong annual changes at certain school sites (school building groups). However, use of individual records 2019/20 for pupils in grades 1 - 3 (primary level) as well as basic level and school attended.</td>
<td>Bern School Administration</td>
</tr>
<tr>
<td>Geneva</td>
<td>Information on socio-professional background of 1st-9th graders in 2019/20 per school as well as digitization of school districts.</td>
<td>Education statistics of the Canton of Geneva; Service de la recherche en éducation (SRED)</td>
</tr>
<tr>
<td>Lausanne</td>
<td>Reconstruction of the catchment areas 2019/20 with the help of individual records on pupils of the 1st - 4th grade (HarmoS counting method of the school years) and attended school.</td>
<td>Education statistics of the canton of Vaud; Unité de recherche pour le pilotage des systèmes pédagogiques (URSP)</td>
</tr>
<tr>
<td>Winterthur</td>
<td>No data on catchment areas, but school districts could be digitized</td>
<td>Geoinformation and Surveying City of Winterthur (stadtplan.winterthur.ch)</td>
</tr>
<tr>
<td>Zurich</td>
<td>Catchment areas (2019/20)</td>
<td>Zurich school board</td>
</tr>
</tbody>
</table>

Table 2 Existing data for the preliminary analyses 2019/20.

Census data 2000: Identification of lower primary school pupils and attribution of foreign language and parents' educational background

The 2000 census dataset (cutoff date 12/5/2000) does not have a feature that contains a pupil's current school year. However, the characteristics 'of compulsory school age' and birthday are included. Therefore, the cut-off date for school enrollment in the respective canton was used for the assignment of the school year. The cut-off dates used in each case can be found in Table 3.

For example, in this study, all children born between May 1, 1993 and April 30, 1994 in the city of Zurich in 2000 are considered 1st graders, and all children born between May 1, 1992 and April 30, 1993 in the city of Zurich in 2000 are considered 2nd graders, and so on. Even if the data do not allow the identification of the actual repetition and later (or earlier) enrolled children, the increased number of cases brings a higher representativeness per school as well as a modeling of alternative catchment areas based on the realistic capacity of the schools. Different grade levels were considered in the study depending on the school system. In the German-speaking cities of Switzerland, 1st-3rd graders were considered (HarmoS school years 3 - 5). In Lausanne and Geneva, kindergarten children were

16 Since data on catchment areas are unpublished, they have not been mapped in any of the cities.
also considered, since kindergarten is attended at the school location and thus a larger sample is achieved. A detailed list of the pupils considered can be found in Table 3.

Since the total number of lower school pupils per catchment area obtained in this way (see section on reconstruction below) was in some cases significantly lower than the number of pupils according to the data on school capacities (see Table 1) (repetition pupils, specially managed classes with an extended catchment area), we also included the youngest children from the assumedly higher class as data points to the catchment area. This was done until our sample corresponded as closely as possible to the official population of each school. The target was the number of pupils not only in the regular classes, but also in the small classes, reception classes and enrollment classes of these school years. This is because for the simulation of the catchment areas, based on the data of the 2000 census, it is not possible to distinguish between children who are to be assigned to one or the other class form. Finally, the total population shows how many pupils can in principle be accommodated in the school in question.

<table>
<thead>
<tr>
<th>City</th>
<th>Pupils considered</th>
<th>Cut-off date for school enrollment 2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basel</td>
<td>1st-3rd graders (HarmoS school years 3-5) and filled with 4th graders from VZ for simulation</td>
<td>April 30 (today July 31)</td>
</tr>
<tr>
<td>Bern</td>
<td>1st-3rd graders (HarmoS school years 3-5) and filled with 4th graders from VZ for simulation</td>
<td>April 30 (today July 31)</td>
</tr>
<tr>
<td>Geneva</td>
<td>1st-3rd graders (HarmoS school years 3-5) and filled up with 4th graders (HarmoS school year 4) from VZ for simulation</td>
<td>July 31 (also today)</td>
</tr>
<tr>
<td>Lausanne</td>
<td>Kindergarten-2nd graders (HarmoS school years 1-4) and filled with 3rd graders from VZ for simulation</td>
<td>August 31 (today July 31)</td>
</tr>
<tr>
<td>Winterthur</td>
<td>1st-3rd graders (HarmoS school years 3-5) and filled with 4th graders from VZ for simulation</td>
<td>April 30 (today July 31)</td>
</tr>
<tr>
<td>Zurich</td>
<td>1st-3rd graders (HarmoS school years 3-5) and filled with 4th graders from VZ for simulation</td>
<td>April 30 (today July 31)</td>
</tr>
</tbody>
</table>

Table 3: Considered class levels and cut-off date of enrollment

The foreign language ability of the individual pupils was determined with the help of the feature "language at home" in the census data set. All pupils who did not indicate German or dialect or French respectively as the language spoken at home were assigned the attribute foreign language.

The 2000 census also contains the attribute highest completed education, which made it possible to determine a person's educational background. In this study, adults with at most a compulsory school leaving certificate were assigned the attribute low educational background.

However, an unequivocal identification of parents of pupils is not always possible with the existing dataset, as parents were only asked about their children's years in the census (limited to the four oldest children). The dataset also does not allow to identify parents who do not live in the same household. Therefore, the (potential) parents were identified in several steps with the help of various characteristic values. Pupils were attributed a low educational background of the parents if all identified (potential) parents had the attribute low educational background.

In a first step, those adults who have children with the cohort of the pupils were assigned as (potential) parents. If single pupils within a household could not be assigned, they were assigned the same (potential) parents as the other pupils in the household. Children who are assigned to collective household types that designate institutions (e.g., old people's homes, boarding schools, residential homes, etc.) and for whom no (potential) parents could be identified in this step were not included in the study.
In a next step, pupils without identified parents were assigned to the two youngest persons in the same household, who are at least 20 years older, as (potential) parents. This age difference was chosen to avoid identifying older siblings as (potential) parents. Again, single pupils in the same household without identified parents were assigned according to other pupils in the household.

Some pupils could not be assigned any parents based on the household information. If those schoolchildren had listed ‘residential homes for workers’ or ‘accommodation for asylum seekers’ in the household type characteristic, they were arbitrarily assigned a low educational background of parents. Remaining schoolchildren without information on the parents' educational background were not included in this study.

In the last step, for pupils who received the attribute low educational background of parents due to a single identified (potential) parent, we considered the educational background of the youngest additional person who is at least 20 years older and has lived in the same household for 5 years. Thus, not only biological parents are included as (potential) parents, but also adults who are very likely to shape the educational background of a pupil.

**Parcellation for reconstructing catchment areas and optimization**

Small spatial modeling units were needed as input for the optimization algorithm to be able to form possible new school catchment areas according to the specifications of the algorithm. For this purpose, different data were used for each city due to data availability and existing spatial city divisions. Table 4 shows the basic data set used for each city. If no street blocks (e.g., small quarters in Bern or statistical blocks in Basel) were available, statistical zones (designation in Zurich) or similar spatial units were used as a starting point and further parceled into street blocks. For this purpose, parcels were formed within the statistical zones, from the street network used for the optimization.

<table>
<thead>
<tr>
<th>City</th>
<th>Base data set for parcellation</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bern</td>
<td>Small quarters</td>
<td>-</td>
</tr>
<tr>
<td>Basel</td>
<td>Statistical blocks</td>
<td>-</td>
</tr>
<tr>
<td>Geneva</td>
<td>Sous-secteurs</td>
<td>Further parcellation with the help of the used road network</td>
</tr>
<tr>
<td>Lausanne</td>
<td>Digitized sous-secteurs statistiques</td>
<td>Further parcellation with the help of the used road network</td>
</tr>
<tr>
<td>Winterthur</td>
<td>Quarters</td>
<td>Subdivision into smaller spatial units based on physical boundaries (roads, water bodies and railroad tracks). Subsequent further parcellation with the help of the road network used.</td>
</tr>
<tr>
<td>Zurich</td>
<td>Statistical zones</td>
<td>Further parcellation with the help of the used road network</td>
</tr>
</tbody>
</table>

Table 4: Base data set per city and methodology for parcellations

These were then further reduced manually according to the principle that no more than 5 lower school pupils may live in a parcel (see Figure 21). This procedure was chosen because, depending on the school, 5 pupils already make up a considerable proportion of the lower school pupils. Larger parcels as modeling units would limit the scope for area swaps between the schools too much during the optimization. On the other hand, peripheral areas were excluded from manual reductions if they could not be assigned to another school with certainty or if more than 5 pupils lived at one and the same address. In these cases, more pupils were admitted.

In addition, some parcels contain more than 5 pupils because the youngest pupils, who were originally assigned to the higher classes, were also included to compare them with the actual school capacities (see previous section).
Reconstruction of the catchment areas 2000/01

As already described in the section on data availability, the catchment areas for the 2000/01 school year had to be reconstructed using the census data on the school attended by the lower secondary school pupils. However, the information on the school attended is not available for all pupils. In addition, information on individual pupils differs from the actual catchment area according to place of residence because they were assigned to a different school at their parents' request or for other reasons. The catchment areas were reconstructed for all schools that had lower-level classes in the 2000/01 school year. In some cases, schools were combined into school groups if they had strong organizational links or shared catchment areas (examples include Weinberg/Turner and Hohl/Kern in the city of Zurich). School units with several buildings on the same school location are considered as one school in this study. The reconstruction does not consider schools that were run exclusively as day schools with city-wide subscriptions, schools that do not have regular classes, and schools that exceptionally ran primary classes in the 2000/2001 school year.

For the reconstruction of the catchment areas, each parcel was assigned to a school. This assignment was made using a combination of different methodological approaches. On the one hand, a 'concave hull' (α-Hull with the standard value $\alpha = 400$ and situationally smaller $\alpha$ values used) was constructed for each school to the pupils with corresponding school information (provided that the residence of the pupils was within the distance of maximum 1 km to this school). In addition, each parcel was assigned to the school to which the majority of the resident lower school pupils go to school. The same was done for each larger spatial unit (meta-level), since catchment areas often respect these administrative borders. Table 5 below lists the meta-level used for each city, according to the designation of the spatial unit by the respective city.
Table 5: Meta-level reconstruction of school catchment areas

<table>
<thead>
<tr>
<th>City</th>
<th>Meta level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bern</td>
<td>Census quarters</td>
</tr>
<tr>
<td>Basel</td>
<td>Districts</td>
</tr>
<tr>
<td>Geneva</td>
<td>Sous-secteurs</td>
</tr>
<tr>
<td>Lausanne</td>
<td>Digitized sous-secteurs statistiques</td>
</tr>
<tr>
<td>Winterthur</td>
<td>Quarters</td>
</tr>
<tr>
<td>Zurich</td>
<td>Statistical zones</td>
</tr>
</tbody>
</table>

For the determination of the catchment areas, the school assignment on the level of the parcel was considered with priority. If no clear majority could be identified for this parcel, but the parcel lies within the concave hull of a single school (the concave hulls partially overlap), it is this school that we assigned. For the remaining cells, the assignment on the higher meta-level (cf. Table 5) was adopted. This semi-automated assignment was then manually completed so that the catchment areas are contiguous and the school capacities can be reached with the increase of as few 4th graders as possible. Consideration was given to how clear the majority is at the parcel and statistical zone level.

Algorithm for the optimization of catchment areas 2000/01

This section supplements the explanations about the algorithm in the chapter data and methods. The selection of the parcels to be taken and/or given away is calculated from the point of view of the school that is taking the turn, using the following algorithm.

General definitions of the algorithm:

- The algorithm generates candidates for each move. A candidate consists of 0, 1, or 2 parcels taken from other schools, and/or 0, 1, or 2 parcels given to other schools. A candidate must give away at least 1 parcel or add 1 parcel.
- All candidates must meet the following conditions to constitute a valid match: (i) the maximum previous school route length in the catchment area of each school affected by a move must not increase by more than the specified percentage, (ii) the catchment areas of all schools affected by the move must remain contiguous, (iii) the maximum school capacities must not be exceeded as a result of the changes, (iv) none of the neighboring schools involved in the move must be further from the mean at the end of the move than at the beginning of the move, if it is already further away from the mean at the start of the move than the trading school, v) none of the neighboring schools involved in the move may have its 'concentration index' increase by more than 7 percentage points if this brings it to a value of more than 40%, vi) the concentration index of the trading school comes closer to the mean as a result of the parcel swap, and vii) no pupil has to pass another school during this swap (min. 50m distance), unless it is an immediately adjacent school (max. 125m from the place of residence).
- The algorithm maintains two lists of candidates: a) the list of final candidates which satisfy all the above conditions and thus represent admissible moves, b) a list of partial candidates which may not satisfy all the conditions. It is possible that candidates are included in both lists.

Sequence of the algorithm:

- The algorithm selects the school that is farthest from the mean as the acting school.
- For each neighboring parcel N of the catchment area of the acting school, the algorithm checks which of the conditions listed above are fulfilled. If condition i) is satisfied, “+N” is added to the list of partial candidates.
If conditions ii) to vii) are also satisfied, "+N" is additionally added to the list of final candidates as a valid candidate.

- For each neighboring parcel N, new candidates "+N+N2" are created from its neighboring parcels N2. If condition i) is met, "+N+N2" is added to the partial candidate list. If additionally conditions ii) to vii) are fulfilled, this combination is also added to the final candidate list as an admissible candidate.

- The list of final candidates thus contains possible moves (candidates) so far, which only adding parcels to the school in action brings its 'concentration index' closer to the city-wide average. All previous final candidates are also present in the partial candidates list. However, the partial candidate list includes additional moves that do not currently meet at least one of the conditions, but where there is a possibility that the conditions could still be met by giving up one or more parcels.

- Subsequently, for all marginal parcels R of the catchment area of the school in action, it is checked whether by pushing off the parcel to a possible neighboring school, the catchment area of the acting school still remains contiguous, and also whether the further criteria i) to vii) are fulfilled. If all criteria are met, "-R" is stored in the final candidate list. In addition, for all existing partial candidates from the corresponding list, it is checked whether they are able to fulfill the criteria i) to vii) in combination with the removal of R. If this is the case, "-R" is stored in the final candidate list. If this is true, the combination (+N-R or +N+N2-R, depending on the partial candidate) is also stored as a candidate in the final candidate list.

- The last step is repeated for a second edge parcel R2 of the school in action, where then also the possible combinations of R and R2 as well as the combinations of the partial candidates with simultaneous removal of R and R2 are tested for the fulfillment of criteria i) to vii). This will then allow the allowable -R-R2, +N-R-R2, and +N+N2-R-R2, respectively, to be included as candidates in the final candidate list.

- In the end, the list of final candidates contains a number of possible and allowed moves, with 0, 1, or 2 parcels added in each candidate, and 0, 1, or 2 parcels given away. This list is sorted based on the absolute deviation of the expected 'concentration index' of the candidates from the mean value of the concentration index. If two candidates have the same score on the expected concentration index, then among the schools affected by the candidates, the one with the largest distance from the mean is searched for and compared to the one where the candidate is closest to the mean (if this results in a tie again, then the school with the next largest distance is searched for and compared, and so on until there is a difference or no more schools are available). In the list sorted in this way, the first list element then represents the candidate with the greatest potential for improvement. This candidate is then returned as the best solution by the algorithm and implemented as a move.

- The acting school is now allowed to make another move, for which the algorithm starts again from the beginning, but does not select a new school. This is repeated until the school cannot make any more moves (no valid candidates can be found for the list of final candidates).

- After all the moves of a school house, the list of all school houses is sorted again based on their updated distance of the concentration index from the city mean, and the algorithm searches in this order for the next school for which a move with admissible candidates can be found.

During the optimization process, a situation may arise where one or more parcels repeatedly move back and forth between two schools. This often happens in the case of two neighboring schools with a very similar concentration index, which means that in each case the school that has just made the move is slightly better off. Since such fluctuations block the optimization process, in certain cases the change of parcels is denied, which stops the fluctuation and allows the optimization process to continue. The change of a parcel from school S1 to school S2 is denied:

- if the parcel belonged to S2 before it was assigned to S1 and this change occurred within the last 25 moves,
or if the number of school house changes the parcel has already passed through is greater than the natural logarithm of the moves played so far, provided that more than 50 game rounds have already been played (num_moves > 50 & num_changes > ln(num_moves)).

The first condition ensures that a parcel cannot be switched back and forth between two parcels too often. Nevertheless, it can happen that parcels are either passed back and forth between three schools, or that several parcels are swapped every 25th turn, which, viewed globally, must also be classified as fluctuation, since this traps the optimization process in an endless loop. The second condition intervenes here, to slow down the permissible number of changes of such fluctuating parcels in the course of the algorithm and to bring the optimization further.

**Footpath networks**

**Length factor**
- 1.25
- 1.5
- 1.75
- 2
- no term

**Crossings**
- suitable
- increased requirement
- demanding
- not recommended

Footpath network and avoided busy roads and forest paths in the city of Basel (2020).
Pedestrian network and avoided busy roads and forest paths in the city of Bern (2020)

Footpath network and avoided busy roads and forest paths in the city of Geneva (2020).
Footpath network and avoided busy roads and forest paths in the city of Lausanne (2020).

Footpath network and avoided busy roads and forest paths in the city of Winterthur (2020)