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Model and Validation Study for Optimizing Students' Positions in Classrooms to Limit the Spread of Infectious Diseases Such as COVID

José Miguel Molina-Jordá

Department of Inorganic Chemistry, University Materials Institute of Alicante, University of Alicante, A-99, E-03080 Alicante, Spain; jmmj@ua.es; Tel.: +34-965903400-2055

Abstract: Classrooms at any educational institution have become high-risk sites for contagion during past and present pandemic periods caused by the SARS-CoV-2 (COVID-19) viral siege, given the prolonged time educators and students spend in joint activity. Among the several strategies employed by educational institutions to minimize the outbreak of contagion are regulating classroom capacity and studying the optimal spatial arrangement of students. The architectural features of each classroom, which include corridors, ventilation components, total volume, and maximum capacity, among other factors, have a direct impact on the risk of human contagion. This work is a proposal to optimize the spatial arrangement of students to minimize the risk of contagion, considering not only the distance between them, but also the different architectural features in the classrooms. The analyses conducted in the different scenarios conclude with a comparison of risk in terms of the arrangement of students that various educators would have used at different education levels in their classrooms based solely on intuitive criteria. The results indicate that in some situations, the locations chosen by educators can double the risk of infection compared to optimal arrangements.

Keywords: modeling; optimization; position in classroom; infectious disease; COVID-19; high school; university

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1. Introduction

Since the last pandemic, caused by the virus SARS-CoV-2 (now commonly referred to as COVID-19), societies worldwide have faced several obstacles. Aside from the immediate health threat, many socioeconomic sectors have had to modify their activities to take the necessary safety precautions to contain the spread of the disease in order to mitigate the dramatic increase predicted for the years 2019–2021 globally. The primary metric adopted by all organizations, including academia, is maximum site capacity. Given the significant impact of the pandemic on society at all levels (social, political, economic, health, and educational) and the fact that some countries remain impacted, additional research is needed on communicable disease containment proposals to protect against the emergence of new viral variants or the outbreak of new infectious diseases.

Academic institutions around the world are feeling the effects of the spread of this pandemic. Although institutions have implemented safety measures such as providing hydrogel hand sanitizers and capacity controls in common areas and classrooms, the numerous cases of contagion in educational institutions have necessitated the implementation of additional measures. Educators worldwide are meticulously redesigning their classrooms, from rearranging seating and changing the appearance of rooms to staggering courses, teaching in smaller groups, and expanding the use of outdoor spaces. Around the world, various schools, high-schools and universities have adopted a variety of strategies to address the issue of decreasing class numbers. Some countries have opted for an online-only education model to prepare for a near future in which the concept of university must be expanded to include the so-called "university without walls" [1,2]. Other countries, such as

Spain, have opted for dual education in 2021, where students alternate between face-to-face and online sessions. This practically solves classroom capacity problems by halving the number of students in each classroom each day. As for hands-on instruction, each educator has the choice of delivering it remotely or in person. However, it appears to be extremely difficult to conduct certain case study activities using online monitoring tools. This is true for lab assignments in disciplines such as physics or chemistry. Thus, it appears that while the digital world has enabled many countries to avoid the issue of confinement during the 2019–2020 and 2020–2021 pandemic academic years, minimal presence is still necessary for a holistic education of students.

When a particular level of class attendance is required, an additional challenge arises: how to organize students in the classroom in such a way that the risk of contagion of this (COVID-19) or other infectious diseases is minimized. The authors of [3] conclude that although there has been some doubt in the literature about the role of aerosols in the spread of COVID-19, their results confirm that indoor airborne transmission is an important factor. Several studies have been undertaken to establish the most acceptable protocols for movement across enclosed and restricted spaces, such as the hallways of education institutions [4]. Additionally, there are studies aimed at optimizing student arrangement in the classroom through the use of nested desks without considering the beneficial factors provided by the presence of ventilation, which is present in almost all classrooms in any educational institution to a greater or lesser extent [5]. Several other studies have concentrated on simulations of the fluid-dynamic conditions in a certain classroom scenario using ventilation data [6–8]. These investigations enable a thorough understanding on the classroom areas that benefit from the most effective air renewal and are therefore the most appropriate for the location of the students. Regardless of their potential utility, conducting research on a specific architectural reality of the classroom requires considerable effort in terms of design and simulation calculation, rendering them impractical for daily use in an educational institution where there are numerous types of classrooms and the capacity of each varies rapidly depending on the academic activity being conducted.

This article proposes a tool for optimizing student distribution in classrooms based on their architectural reality. The tool is composed of a straightforward computation approach that has been integrated into a widely used software program (Microsoft Excel, from the Microsoft Office 2021 software package). This tool enables the optimal distribution of students in the classroom to be calculated with the least amount of effort and time possible (1–2 min), considering the unique characteristics of each classroom (the presence of corridors, the location of ventilation inlets, etc.). The computation tool was created to minimize student and educator contagion in order to prevent the spread of an infectious disease. The optimized outcomes were compared to the classroom arrangements used by educators in high-schools and universities. The findings emphasize the importance of following protocolized procedures when arranging students in classrooms, as arrangements made by educators based on their personal criteria have occasionally resulted in a cumulative risk to individuals in the classroom that is more than double that of the optimized arrangements.

2. Methodology

2.1. Description of the Context and Participants

The current study enlisted the assistance of multiple individuals from various academic institutions in order to collect information from different educational classroom settings. There was a total of 21 participants, including 10 secondary (high school) educators and 11 professors from various disciplines in higher education (university). The following Spanish institutions served as partners: The Institute of Secondary Education "Pare Vitoria" High School (Alcoy, Spain), the Valencia Polytechnic University (Campus de Alcoy—Alcoy, Spain), the University of Valencia (Campus dels Tarongers, Valencia, Spain) and the University of Alicante (Campus de San Vicente del Raspeig, San Vicente del Raspeig, Spain).

2.2. Method

The purpose of this work is to determine the optimal organization of students in a classroom in order to minimize the risk of transmission of illnesses such as COVID. A three-step approach was adopted for this objective. To begin, educators in different institutions were asked how they would arrange ten students in classrooms measuring 7 × 5 m in total, but with varying ventilation layouts and a designated space for the educator. This information was gathered using specially designed templates, and the challenge of filling them in was having to rely entirely on intuition, without the assistance of calculation tools. The study on the intuitive position of students is relevant and necessary to justify the need for a model that optimises the position of students to minimise the risk of transmission of an infectious disease such as COVID-19. This analysis makes it possible to compare the pedagogical reality in classrooms during the pandemic, which was that students were placed in positions intuitively chosen by the educator. Second, a model was developed to optimize student positions, considering their distance from one to another, their distance from the educator, and, if the classroom is ventilated, their distance from the ventilation points. Finally, in the third phase, the data from the opinion of the educators were compared to algorithmically computed arrangements to assess whether intuition can be relied on in a scenario as dangerous as the spread of a global viral epidemic such as COVID.

2.2.1. Data Collection

Educators who took part in this study were provided with templates depicting schematic designs of classrooms. The configurations examined were: classrooms without windows (equivalent to classrooms with insufficient or inefficient ventilation) and classrooms with four windows set in various positions. Educators were required to plan a classroom arrangement for 10 students in a 5 × 5 m classroom in order to minimize the risk of COVID transmission. The educator was given a 5 × 2 m space and is believed to have maintained a fairly constant position in the centre of it. The data collection templates are presented in Figure 1. Figure 1 shows the different scenarios examined, which replicate the architecture of the classrooms used for the experimental studies.

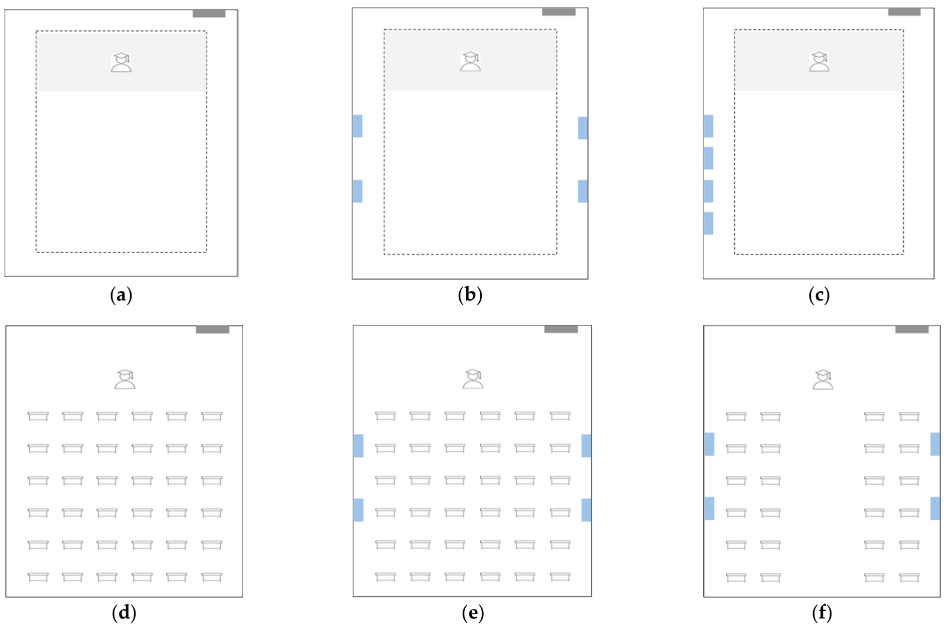


Figure 1. (**a**–**f**) Data collection templates distributed to educators. The grey rectangle represents the entrance door, which for the purpose of this calculation is considered inactive (closed). The blue rectangles represent windows that are considered fully open. The capacity adopted in this study of 11 people in a classroom with a total capacity of 37 people is considered acceptable in accordance with the restrictive measures imposed by the Spanish government at the time of the study.

2.2.2. Proposed Model for Calculating Cumulative Risk

It is challenging to offer mathematical models for distance optimization in various situations since there are no (or very few) simple formulas for predicting the potential risk of each student and educator in a classroom as a function of the various variables that may affect it. Recent work, such as that of [3], defines risk as a function of the square of the distance between two persons. While this type of expression has the advantage of being extremely simple to use, it has the problem of ignoring the effect of other critical aspects such as ventilation, which has been emphasized as a critical factor in limiting the spread of airborne infections.

In this study, we use the well-known Wells–Riley model expression for predicting transmission risk [9]:

$$\mathrm{R} = 1 - \exp\left(\frac{-\mathrm{Iqpt}}{\mathrm{Q}}\right) \tag{1}$$

where R denotes the probability of infection (risk), I denotes the number of infected individuals, p denotes the lung ventilation rate of each individual likely to be infected (we use a standard value of p = 0.3 $\mathrm{m}^3\mathrm{h}^{-1}$ for people who are seated or active in enclosed spaces [10]), q denotes the rate at which an infected person generates "quanta" or viral load emitted to the environment per unit time (quanta$\cdot\mathrm{h}^{-1}$) and t denotes the exposure time (we take a value of 1 h, which is a reasonable value for a time unit of academic activity). Q in Equation (1) is the room ventilation rate with germ-free air in $\mathrm{m}^3\mathrm{h}^{-1}$. The results in [11] showed that high quanta emission rates (>1.6 quanta/s) can be reached by a symptomatic infectious SARS-CoV-2 subject performing vocalization during light activities (i.e., walking slowly) whereas an asymptomatic SARS-CoV-2 subject in resting conditions mostly has a low quanta emission rate (<0.016 quanta/s). Based on the findings in [7], a value of 0.238 quanta/s was taken, which corresponds to an environment where people are seated, without much interaction among them. The q value was then kept as a constant to project the infection probability and the required ventilation rate for similar confined spaces. The original Wells–Riley paper [9] defines expression (1) as taking ventilation into account as a critical parameter for calculating the risk probability under the assumption of well-mixed air. Because expression (1) includes the time variable in the risk factor, R is not only dependent on the distance between two persons but also on the amount of time elapsed during the risk analysis. Using the Wells–Riley model, a number of papers have been published on airborne transmission of infectious diseases (many of which predate the COVID pandemic). As an example, we can cite the works based on the analytical use of this model [12–15] or those that incorporate it in computational fluid-dynamic calculations [16,17], or some studies that modify this model to make it transient and thus overcome its limitations of being based on the fact that the air in a confined space is in a steady state and is fully mixed [7,18]. Not just ventilation has a beneficial effect on the risk of contagion [19–21]. Maintaining an acceptable distance between persons has been recommended as one of the most effective methods to avoid disease transmission during the COVID pandemic [4,5,7,22]. Numerous more variables alter the analysis. One subset of these variables is related to individual characteristics such as gender and infection susceptibility, physical condition, age, and level of defences, among others. These variables are complicated to consider since they require knowledge about each individual and yet their systematization for the placement of each student in the classroom is very complicated. Another set of variables relates to environmental conditions. This setting includes not only the immediate educational environment (the classroom) but also the geographical location of the education centre on the globe, which influences the climatology and its temporary pandemic effect. Long-term exposure to air pollution was associated in [23] with stronger antibody response among infected individuals, probably reflecting higher viral exposure and disease severity. However, probably the most critical aspect is the conditioning of the classrooms to maintain clean indoor environments. The primary determinant is the presence of natural air intake ventilation in classrooms and hallways. It has been observed that properly ventilated spaces can reduce considerably the danger of infection [6].

The effect of indoor ventilation on the risk of contagion is extremely difficult to analyse because it is dependent on changing environmental factors such as air flow rate, which is determined not only by the size of ventilation windows but also by changing climatic factors throughout the day, such as local wind speed [24,25]. One of the most often-used measures for quantifying the effectiveness of interior ventilation is the term "air changes per hour", or ACH, which is defined as the air volume added to or removed from a space in one hour [26–29]. In metric units, ACH is calculated as follows:

$$\mathrm{ACH} = \frac{3.6 \cdot \mathrm{Q}}{\mathrm{L} \cdot \mathrm{W} \cdot \mathrm{H}} \tag{2}$$

where Q is, as already noted, the volumetric flow rate of air entering the room per unit time (measured in $m^3 s^{-1}$ in the International System, but commonly expressed in litres per hour or l/h), and L, W, and H are the room's length, width, and height, respectively. It is critical to understand that an ACH of 1 h^{-1} does not imply that 100% of the air in the room is replenished in that time period. This is only true in rooms where the air is refreshed every hour. This would be valid only in rooms that match the parameters of the so-called "plug flow" hypothesis, according to which the existing air is moved without mixing with the new air [27]. The reality is more complicated, as incoming and exiting air are in fact mixed. A more accurate approximation is made by the authors of [30], who interpret the following expression as the fraction of initial air (X^{air}) remaining in the room after a period t:

$$X^{air} = e^{(-\mathrm{ACH} \cdot t)} \tag{3}$$

Following Equation (3), the fraction of original air left after 1 h is X^{air} = 0.36, or 36%, and after two hours this number drops to only 14%.

Several of the published research on the effect of ventilation on the risk of contagion go so far as to propose exceedingly extensive analyses that account for a variety of environmental variables, including temperature, atmospheric pressure, ultraviolet light, and the ACH parameter. None of them, however, consider anything as broad as the distance between an individual and the point of ventilation. Windows that allow for ventilation have two distinct effects in a confined environment. On the one hand, the overall result is a re-circulation of air throughout the room during a specified time period (this is the effect so far considered in current studies on contagion risk). On the other hand, and maybe more significantly, there are local effects on individual occupants of the space. The aforementioned plug flow concept [27], which assumes complete air renewal, is true in a very small number of circumstances, which may be restricted to classrooms with ventilation on at least two of the opposite walls of the enclosure they enclose. Convective factors make it much more difficult to renew air much in conventional classrooms with a single row of windows, with the difficulty increasing further away from the ventilation point.

In this case, the cumulative risk R in Equation (1) is proposed to be dependent on the distance to the aeration point. This implies that each individual establishes an imaginary region confined by his or her distance to the nearest aeration wall (P), the closest aeration point distance (D), and the classroom's height (H). Numerous studies indicating the difficulty of air exchange in confined environments when located far from the aeration point [24–30] support this working hypothesis. In this work, the expression for the "infection risk" has been consequently modified to include interpersonal distance and ventilation as two critical risk factors. For the purpose of calculating the risk associated with each individual, the expression (1) is adjusted as follows:

$$R_i = 1 - \exp(-R_{di} \cdot R_{Qi}) \tag{4}$$

where R_{di} and R_{Qi} denote the risks associated with each individual arising from the two examined motives of interpersonal separation and ventilation, respectively. R_{di} and R_{Qi}, on the other hand, can be determined using the following expressions:

$$R_{di} = \sum_{j}^{N} \left(-18.19 \cdot \ln\left(d_{j \to j+1}\right) + 43.276\right)/100 \tag{5}$$

$$R_{Qi} = \sum_{k}^{N} \frac{Iqpt}{Q_k \frac{ACH_{i-k}}{ACH_{62.1}}} \tag{6}$$

where ACH is the "air changes per hour" parameter. We recall here that the distance between two points of interest (e.g., the distance between two persons) located in X and Y coordinates is calculated by the following expression:

$$d = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2} \tag{7}$$

Equation (5) comes from an adjustment of the transmission probability based on the droplet distribution as a function of interpersonal distance [7]. Equation (6) is based on the proposal of the modified Wells–Riley model [7], which defines an air distribution effectiveness parameter, here computed as the ratio $ACH_{i-k}/ACH_{62.1}$. The subscripts $i-k$ and 62.1 relate to each individual position and to the ASHRAE Standard 62.1-2019 [31]. ACH62.1 has taken a value of 4 to ensure a proper clean environment. The parameter ACH_{i-k} can be determined by assuming that each individual defines an imaginary space with regard to the nearest ventilation point, based on his location in the classroom, such that:

$$ACH_{i-k} = \frac{3.6 \cdot Q}{P \cdot \frac{\sqrt{D^2 - P^2}}{2} \cdot H} \tag{8}$$

Thus, the cumulative risk model discussed in this study is composed of straightforward expressions that enable optimal arrangement of students in the classroom in order to minimize their risk of infection. Equations (5) and (6) are not intended to be reliable expressions of individual risk because, as previously stated, it is extremely difficult to account for all the variables that contribute to this risk parameter, particularly when some of them are highly variable at any given time, such as the unforced air flow through the ventilation points. This model satisfies the physical constraints imposed by the context under consideration. Given that H is a parameter that is typically between 3–5 m, the most critical variables are P or D, which, when very high (person is located far from the ventilation point), indicate that the risk R is not minimized by the influence of ventilation. When D or P are small, as when an individual is near a window, the risk R becomes zero. As a result, this suggested model accounts for ventilation effectiveness as a function of distance to ventilation points, a factor that has previously been overlooked in even the most sophisticated models of contagion risk.

2.2.3. Implementation of the Proposed Model in a Calculation Tool

It is straightforward to extract optimized solutions to Equations (6) and (7) using an automated computation tool. This study made use of the Excel calculation tool included in the Microsoft Office package for Macintosh. Two distinct computation scenarios were used. In classrooms where the location of desks is adjustable, it is sufficient to establish initial positions in Excel for each of the ten students and the educator (who is considered to be in a fixed position). For each individual, the spreadsheet calculates the distances and cumulative risk. The Excel Solver tool is used to identify the optimal positions for the ten students that minimize the total risk for all individuals present, namely the ten students and the educator. In classrooms with set table locations that may or may not feature aisles without desks, a separate procedure should be utilized. Excel organizes and numbers the desk locations. If there are no aisles in the classroom, there are 36 desks overall, and each desk is assigned a number between 1 and 36. When aisles are present, the number of desks varies according to the classroom configuration. The Solver tool generates ten random numbers ranging between 1 and the maximum number of desks and determines the locations with the lowest cumulative risk.

The Solver tool offers three different calculating algorithms. The "Evolutionary" method was chosen because it is the most powerful but also the most-time consuming of all. The evolutionary process uses the theory of natural selection, which works well because the best outcome is already known. It starts with a random "population" of sets of input values. These values are fed into the model and the outcome is compared to the target. They are chosen to establish a second population of "offspring" that are closest to the target number. The input values of the initial population are "mutated" into the offspring. The evolutionary calculation conditions were as follows: convergence = 0.001; mutation rate = 0.1; population size 3000; maximum time without improvement = 300 s.

2.2.4. Quantification of Risk Using Data Gathered in Handwritten Templates

A digitisation tool called WebPlotDigitizer was used to quantify the accumulated risk from the templates filled out by the various educators and compare it to the optimized risk. This tool, which runs on a Macintosh, allows for the coordinates of the different student locations chosen by the educators on the basis of intuition. The cumulative risk for each of these coordinates, as well as the overall risk, was determined using the developed Excel tool in order to compare it to the results of the optimized calculation.

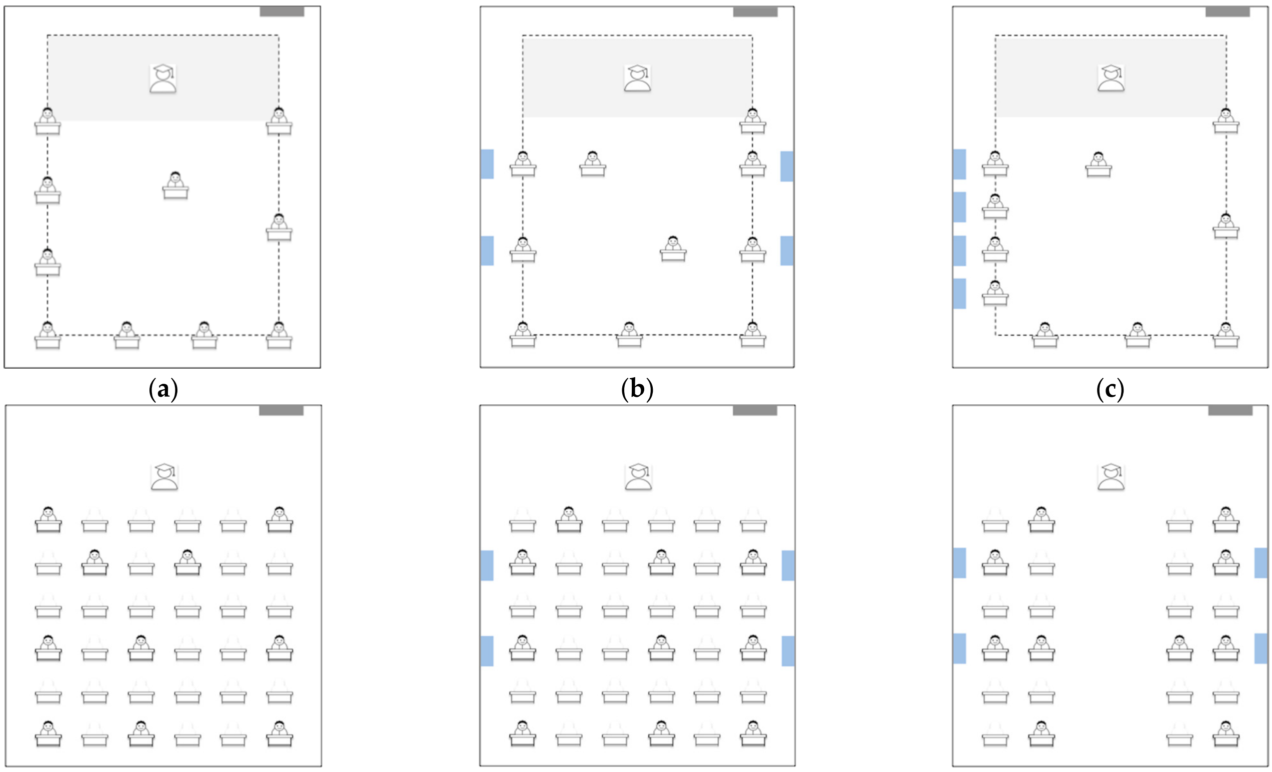
3. Results and Discussion

The following are some instances of classroom configurations in which student and educator positions have been optimized to minimize the risk of contagion.

Without ventilation, it can be seen that the optimal distribution of students maximizes their distances. In case someone required more distance (e.g., the educator is elderly or considered at risk) the distance between students would be compromised by this person maintaining a greater distance from the students. In ventilated classrooms, the optimal arrangement emphasizes locating students near ventilation points.

There is a significant difference in the location of students between the two conditions represented by the classroom with a free arrangement of desks and the classroom with a predetermined arrangement (desks anchored to the floor). The calculated risk for classrooms with free-standing desks is 5% lower, as they allow desks to be positioned in the optimized locations with the lowest risk. Aisles and other architectural barriers (e.g., fixed cabinets, fixed location equipment, etc.) are elements that increase risk contagion since they impair the possibility of arranging students in optimal configuration. Another important issue is that calculations show revealing results regarding the beneficial effect of aeration points. The environment with the lowest risk of transmission is a ventilated classroom with unrestricted seats configuration. Unventilated classrooms are clearly unacceptable conditions, as the cumulative danger is approximately 4–5 times that of a ventilated classroom.

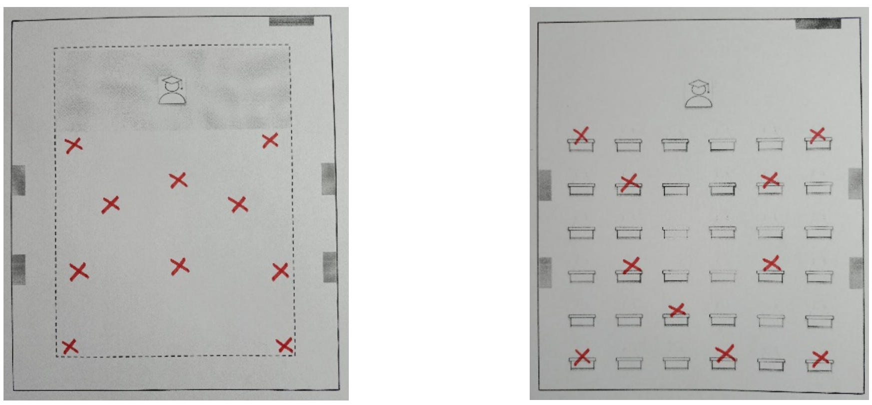
The graphs in Figure 2 were compared to those created by educators who did not utilize any mathematical tool. These graphs compile the perspectives of educators on how to arrange students in the classroom solely based on intuition and knowledge gleaned from support manuals and other resources released by various Spanish media outlets and government agencies. The data for these graphs were gathered by assigning educators in two distinct choice environments: (i) individual choice: the educator has a maximum of ten minutes to make a personalised, free, and non-consensual decision with other educators; and (ii) consensual choice: educators meet in groups of three between twenty to twenty-five days after making the individualised choice and have a maximum of twenty minutes to reach a consensual solution. A condition of the consensus decision is that educators are prohibited from discussing their individual selections on the days between the two options.



(**a**) (**b**) (**c**) (**d**) (**e**) (**f**)

Figure 2. Optimized student positions in classrooms with the following environments: (**a**) classroom with free seating arrangement without ventilation; (**b**) classroom with free seating arrangement and facing windows; (**c**) classroom with free seating arrangement and windows in a wall; (**d**) classroom with pre-set seats without ventilation; (**e**) classroom with pre-set seats and facing windows; and (**f**) classroom with pre-set seats, facing windows and corridor.

Figure 3 illustrates a few exemplary graphs collected from the educators who took part in this study using the personalised choice test.



(**a**) (**b**)

Figure 3. Examples of arrangement templates collected as feedback from educators participating in this study in the individualised choice test for the following configurations: (**a**) classroom with free seating arrangement and facing windows, and (**b**) classroom with pre-set seats and facing windows. A red cross indicates the position of a student.

A total of 126 plots were examined across the six environments examined in this study. No significant differences were found between the two modes, individual and consensual, of filling in the templates. The cumulative risk for each environment was estimated from the digitized seating positions and compared to the optimal cumulative risk. The outcome of the comparisons is depicted in Figure 4, which plots the normalised frequency of the cases analysed against the relative cumulative risk.

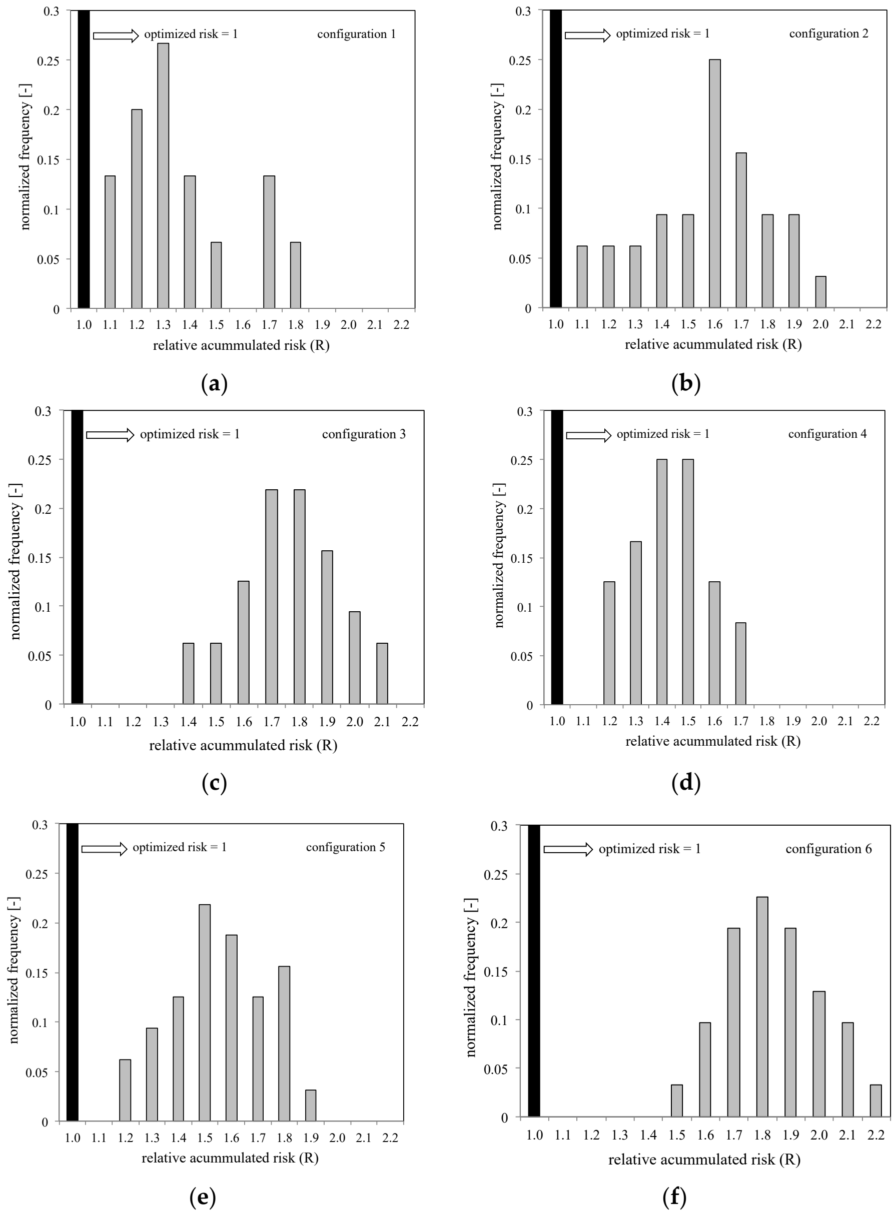


Figure 4. Cumulative risk distributions of the arrangement templates developed by educators relative to the risk achieved by an optimal arrangement for the following environments: (**a**) classroom with free seating arrangement without ventilation; (**b**) classroom with free seating arrangement and facing windows; (**c**) classroom with free seating arrangement and windows in a wall; (**d**) classroom with pre-set seats without ventilation; (**e**) classroom with pre-set seats and facing windows; and (**f**) classroom with pre-set seats, facing windows and corridor.

It is worth noting that the absence of a calculating model forces the educator to rely on intuition about the arrangement of students, which frequently increases the risk of transmission for both the students and the educator. This risk increases significantly when classrooms include architectural features such as corridors. Additionally, it is noted that the intuition of educators for adequate student arrangement diminishes in the presence of aeration points (windows) as they do not fully exploit the advantage these points provide and may introduce additional risks that could be avoided by using an optimization technique such as the one provided in this work.

The primary outcomes of this risk calculation work were finalized in October 2019. These findings were then used to collect data on COVID-19 disease transmission across different educational institutions and settings throughout the second semester of the 2020/2021 academic year. To accomplish this, study groups and control groups were established in various educational institutions, and the cumulative incidence of infected individuals who tested positive in PCR tests was determined. Each school had a research group and a control group assigned to identical classrooms arrangements and, consequently, identical ventilation options. Attempts were made to maintain gender equity within these groupings. As detailed in Table 1, the study was conducted in a variety of classroom settings. The data in Table 1, which were collected by the various educational centres, were not subjected to any intentional or unintentional mathematical manipulation. It is interesting to comment on some of the issues relating to the data in Table 1. In general, it can be observed that the study group performs better than the control group, despite the limitations associated with this study (which will be discussed in Section 4, one of the most important being the fact that educational centres are not closed systems and the infections can have a foreign origin). In the case of men, the study group performs significantly better in five of the seven centres (in U2 and U4, the results are roughly comparable). In the case of females, the results obtained in HS2 and U4 are analogous, and it can also be observed that the study group improved the results of the control group only in five of the seven centres.

Table 1. Cumulative incidence (number of infected students) in various classroom contexts. The term "CC" refers to the classroom configuration (the letters correspond to the configurations shown in Figure 2). The codes refer to: HS1, HS2 and HS3—classrooms at the Secondary Education "Pare Vitoria" High School (Alcoy, Spain); U1—classroom at the Valencia Polytechnic University (Campus de Alcoy—Alcoy, Spain); U2—classroom at the University of Valencia (Campus dels Tarongers, Valencia, Spain); and U3 and U4—classrooms the University of Alicante (Campus de San Vicente del Raspeig, San Vicente del Raspeig, Spain).

Centre	Code	CC	Control Group: Classroom with Non-Optimized Student Arrangement				Case Study Group: Classroom with Optimized Student Arrangement			
			Number of Students		Accumulated Incidence		Number of Students		Accumulated Incidence	
			M	F	M	F	M	F	M	F
High-School	HS1	C	12	15	3	2	14	12	2	1
	HS2	A	15	9	2	2	13	10	3	2
	HS3	C	14	17	4	3	21	17	2	1
University	U1	E	28	26	6	5	32	22	3	2
	U2	C	13	18	4	4	18	18	2	2
	U3	F	17	15	8	2	14	12	1	1
	U4	F	32	25	9	7	28	28	4	3

The following paragraphs describe the conditions under which this study was conducted:

- Both the control and study groups adhered to the general protocols established by each centre, which are consistent with the general guidelines of the Spanish Ministry of Health. These guidelines include the use of face masks inside and outside the classroom, as well as dispensers of hydroalcoholic gel in each classroom.
- The study group adhered to a strict protocol for entering and exiting the classrooms, as suggested by some authors [3], who emphasize the importance of maintaining interpersonal distance throughout the classroom corridors until reaching the study tables.

Although the data in Table 1 should be interpreted cautiously, they are sufficiently revealing. There appears to be clear evidence indicating a slight but significant decrease in incidence in the study groups as a result of students being placed in optimal classroom positions. Additionally, males have a higher incidence than females in both high schools and universities, with the later exhibiting the greatest gender disparity in incidence.

As a result of the findings in Table 1, it appears that optimizing student seating arrangements has a beneficial effect on containing the spread of infectious diseases such as COVID-19. The fact that this effect is more pronounced among younger age groups of students (i.e., in high schools) could be attributed to a number of factors. One of the most significant reasons for this was identified in this study as the formation of groups that jeopardize safe distances at classroom exits (in corridors and playgrounds). Indeed, a study was conducted to ascertain the average number of students identified in groups at classroom exits. By and large, it was observed that these groups formed outside of classrooms in high schools had a larger average membership than those formed in universities (Figure 5). Extremely large groups have been discovered in high schools that failed to maintain a safe distance and whose members did not even wear safety masks (Figure 5d). These groups were predominantly composed of males, which could explain the slight bias of higher contagion in males seen in Figure 5a,b. At this point, it is also necessary to recall studies such as [32], which state that clinical studies have shown that women are less susceptible to viral infections due to higher macrophage and neutrophil activity, antibody production and response.

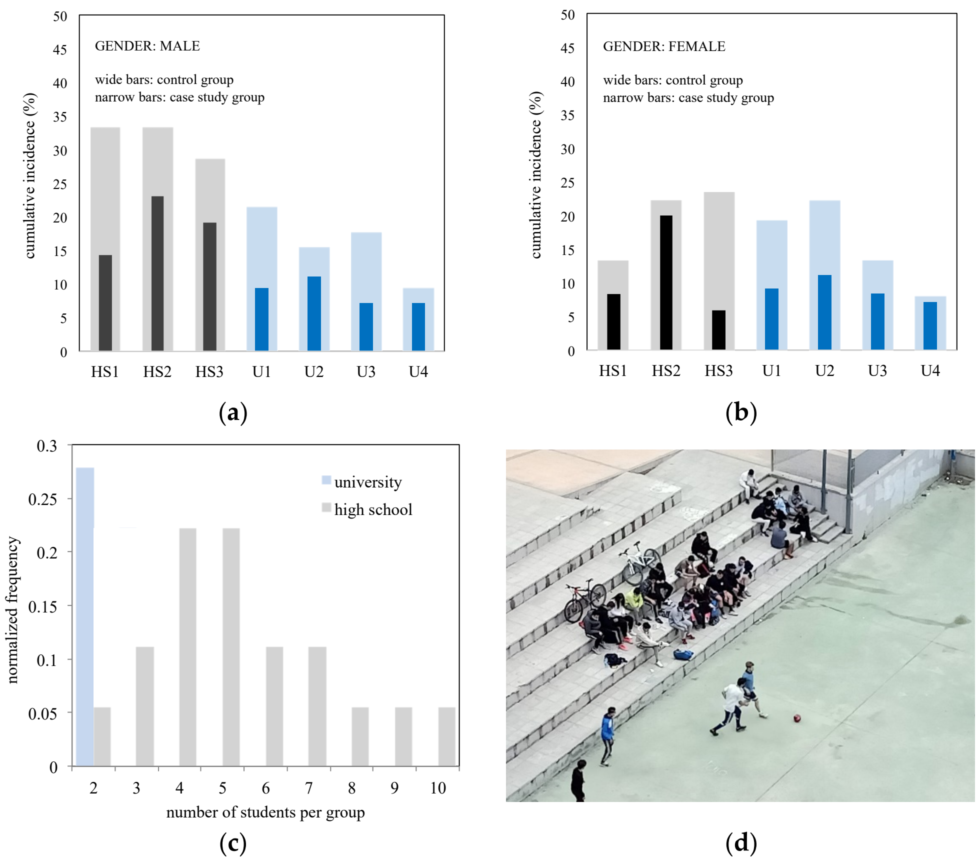


Figure 5. (**a**,**b**) Cumulative incidence of detected infection cases for the control group and the study group in the different high school (HS1–HS3) and university (U1–U4) contexts for males (**a**) and females (**b**); (**c**) normalized frequency of the number of students forming recreational groups in high school and university; (**d**) example of group formation in high schools where members clearly do not maintain a safe distance.

Without a doubt, the most significant risk factor in the secondary schools that participated in this study was not the classrooms themselves, but rather the entrance and exit of the classrooms, as well as break times, during which pupils expressed a certain lack of awareness regarding their health status. However, the situation has been quite different at university. University students seem to be more aware of the pandemic situation and create less health risks by always wearing masks and avoiding safety risky group formations due to the lack of social distancing. Because of the greater precaution of these students, any action taken to prevent the spread of the disease will be more effective. In any case, the application of a student arrangement model such as the one described in this research seems to be important in preventing the spread of an infectious disease such as COVID-19 in the classrooms of any educational institution.

4. Comments on the Limitations of This Study

This study provides a simple and quick articulation proposal that educators can use to position students in classrooms in order to limit the risk of infectious disease transmission. In the majority of educational centres, the study group performed better than the control group, as can be seen in Table 1. However, the author would like to highlight a few essential issues that may aid in comprehending the associated limitations faced by the various educators who participated in the study.

On the one hand, students were informed that they would be participating in a study and their consent was obtained (in the case of minors, parental consent was sought). While this is true, each student did not know whether he or she belonged to the study group or to the control group, because students did not know whether the positioning suggested by the educator upon entering the classroom was based on an optimised distribution calculated with the proposed model or on the educators' intuition. Nonetheless, it is possible that the students who felt they were part of the study changed their health behaviours slightly, which could have altered the results in both the study and control groups.

Another issue that may influence the outcomes and their comparison, and that is addressed in the text, is the difference in health protocols between the centres. In this regard, it is important to note that the involved universities had more numerous cleaning staff that disinfected classrooms more frequently than high schools. In addition, in the case of the University of Alicante, which has a fairly large campus with green areas and is located relatively far from the city centre, the cumulative incidence of infectious cases seems to be lower than in other educational centres. The other educational institutions are embedded in urban areas, and it is possible that environmental pollution contributes to an increased propensity for transmission. Seasonal factors can be excluded because data collection on infected individuals was conducted at the same time of year in all participating educational centres (second semester of the 2010/2021 academic year).

In addition, it should be kept in mind that the study and control groups are not closed groups, as students also communicate with siblings, parents, relatives, and friends outside of educational institutions. Therefore, it is extremely difficult to distinguish between infectious disease transmission inside and outside the classroom. This could have serious implications for the results obtained in the work, as the present study assumes that the infections recorded originate in educational centres. The reduced confidence on the gathered data dictates that any computed results should be read with caution. Nevertheless, it is reasonable to assume that at the time of the study, there were virtually no extracurricular activities in the educational centres that could contribute to the spread of disease. In addition, although the behaviour of the parents of students during time spent at home can be considered mature and conservative in terms of safety standards, family households can be considered as infection hotspots due to the confluence of family members who have been exposed to infected individuals during their regular activities. The youngest members of the family, who come to educational centres with possible infections of various origins, including family origin, make these centres important sources of COVID transmission due to the limited classroom space that students must share during long academic teaching days. Despite the limitations noted above and considering that this study can be extended to obtain data on larger populations, the results presented here are sufficiently informative to show that there was a positive effect of optimizing the positioning of students in the classroom, so the author believes that it would be beneficial to use the model and tools proposed for future infectious disease containment actions.

5. Conclusions

This article presents a straightforward technique for optimizing classroom student arrangement that can be applied to a variety of architectural situations. The model emphasizes the importance of classroom ventilation in reducing the risk of contagious disease transmission. Cumulative risks associated with the model-derived arrangements are up to 100 percent lower than those associated with intuitive student arrangement. Monitoring control and study groups in various educational centres have been used to account for the effects of this optimized design. The results indicate that the proposed approach has a greater effect in the university context than in the high school context, which could be explained by the fact that university students have a higher level of health awareness, as they maintain social distancing even outside the classroom and always wear masks.

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