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Remote Teaching of Experimental Chemistry in Developing Countries

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Abstract: During the ongoing 2020 CoVid-19 crisis, the use of remote meeting technologies such as Zoom™, Microsoft Teams™ and Google Meetings™ has been paramount to theoretical teaching in a safe socially distanced environment. However, several problems arise when there is a need for an experimental approach. This paper looks at one of the possible solutions, including how to best separate the students, how to minimize close interactions and how a mixed environment of remote/presential teaching is required, minimizing the amount of extra materials, resources and protection equipment required, such that developing countries can quickly adopt this method, without the purchase of any external equipment.

Key words: CoVid-19, experimental chemistry, remote education, education, Zoom, laboratory, social distancing.

1. Introduction

Throughout this pandemic, as experimental chemistry professors we need to carefully balance several aspects of our teaching, these aspects encompass to name a few:

(1) Safety aspects

(2) Enrolment and student dropout aspects

(3) Teaching aspects

(4) Budget aspects

It is challenging at the best of times to keep a healthy economy in our universities, where students are meant to learn as much as possible from the already decaying experimental chemistry, however the effects of this pandemic have left us in uncertainty, uncertainty for our student body, uncertainty for the safety of ourselves and our colleges and uncertainty of our jobs. Using a remarkably simple questionnaire in the organic chemistry department of the University of Mexico, we found that our professors have the following concerns:

(1) How will I keep safe from CoVid-19?

36% of respondents

(2) Will I have to teach more hours?

10% of respondents

(3) Is my job at risk?

12% of respondents

(4) How am I supposed to teach experimental chemistry remotely?

28% of respondents

(5) Other

14% of respondents

With the results of this questionnaire, and the main concerns identified in our community, we decided to form a guideline for the teaching of experimental chemistry.

(1) The safety of the professors, students and supporting staff must be the top priority.

(2) The guideline would have to be simple enough to be able to be explained over a remote meeting or a printed flow chart.

(3) Because of the lack of a presential administrative team, the data required for any

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calculation must be able to be obtained in a simple way (a Google spreadsheet shared between all students and all professors, or an excel spreadsheet that is filled by the professors and then collated by the head of the department).

(4) The requirement for any extra equipment must be kept to a minimum.

2. Historic Background

2.1 Black Plague

There is little written about guidelines during previous pandemics, a quick Google search (as libraries are currently closed) only yielded accounts of Britain in the 14th century, when the Black Death struck Europe, killing off half the population, the University of Oxford, in response to the plague, students and lecturers fled the city [1].

The plague did not end in the 14th century, as we know, the plague would return over the next couple of centuries, however universities had to adapt to the new disease, and by the 15th century, Oxford University students created informal escape plans to escape the university town whenever plague struck, during this period, countryside manors became the "remote education" places for escaping students [2].

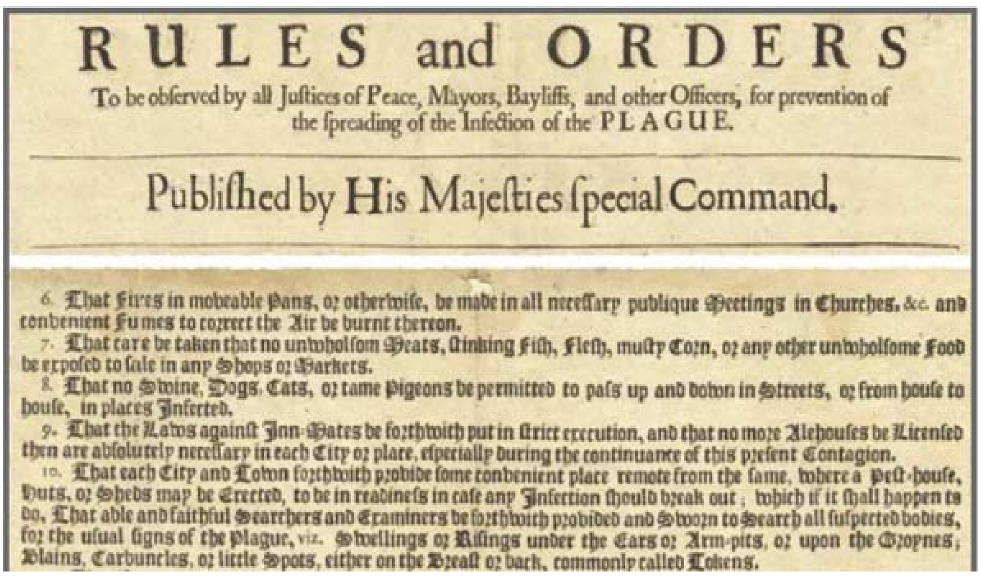
In 1666, King Charles II published a set of rules [3], for the control of the plague in England, this only happened after more than 7,000 people perished in London (Fig. 1).

However, no single mention of universities or any guideline was found in these rules, let alone any mention of experimental chemistry.

2.2 Spanish Influenza

The only mention of a university that we were able to find was from Stanford University, where their safety measures resulted in:

"According to the Stanford Historical Society's *A Chronology of Stanford University and Its Founders*, in April 1918, those affected by the flu on campus were promptly isolated and hospitalized, resulting in a lower percentage of deaths than experienced elsewhere. Six out of 260 cases resulted in death. The flu affected greatly a campus already experiencing disruptions due to World War I…*The Stanford Century*, published by the Stanford Alumni Association in 1991 and written by alumna LINDA PETERSON, described the flu masks as "made of cheesecloth, looped over the years, they were sold for a dime a piece" [4]. (Chesley, 2018)


RULES and ORDERS

To be obſerved by all Juſtices of Peace, Mayors, Bayliffs, and other Officers, for prevention of the ſpreading of the Infection of the PLAGUE.

Publiſhed by His Majeſties ſpecial Command.

6. That Fires in moveable Pans, or otherwiſe, be made in all neceſſary publique Meetings in Churches, &c. and convenient Fumes to correct the Air be burnt thereon.

7. That care be taken that no unwholſom Meats, ſtinking Fiſh, Fleſh, muſty Corn, or any other unwholſome Food be expoſed to ſale in any Shops or Markets.

8. That no Swine, Dogs, Cats, or tame Pigeons be permitted to paſs up and down in Streets, or from houſe to houſe, in places Infected.

9. That the Laws againſt Inn-Mates be forthwith put in ſtrict execution, and that no more Alehouſes be Licenſed then are abſolutely neceſſary in each City or place, eſpecially during the continuance of this preſent Contagion.

10. That each City and Town forthwith provide ſome convenient place remote from the ſame, where a Peſt-houſe, Huts, or Sheds may be Erected, to be in readineſs in caſe any Infection ſhould break out; which if it ſhall happen to do, That able and faithful Searchers and Examiners be forthwith provided and Sworn to Search all ſuſpected bodies, for the uſual ſigns of the Plague, viz. Swellings or Riſings under the Ears or Arm-pits, or upon the Groynes; Blains, Carbuncles, or little Spots, either on the Breaſt or back, commonly called Tokens.

Fig. 1 Sample of the Rules and Orders published in 1666 by King Charles II for the prevention of the plague.

However, to the best of our knowledge no guidelines, account of any implementation of experimental chemistry was found in our historical research. This might be due more to the lack of journals in our closed libraries, than anything else. However, we must stress that it is by no means by lack of effort that we could not find any sources online, during these unprecedented times, one must adjust to the available resources.

2.3 Objectives

(1) Ensure the safety of students, professors, researchers and supporting personnel;

(2) Minimize the use of materials and resources;

(3) Maximize the number of students that can be in the laboratory at a single moment.

3. Methodology

3.1 Clustering Students

The safety of students, is fundamental to the sustenance of any university, we must ensure that in these difficult times our university does not become an infection vector, as it would be catastrophic on human and economic terms.

Therefore we propose a method of "safety bubbles" to be applied in our laboratories. "Safety bubbles" [5] is a term coined in British primary schools, where a single group of students is subdivided and treated as a separate entity, e.g. the class of year 1 will be further divided into 1-A, 1-B, 1-C…1-X in manageable groups of 5-10 students, according to the social distancing capabilities of the classroom and the availability of staff.

However, unlike a primary school, most experimental chemistry laboratories will have students from different semesters, so it is unlikely to have a clean, equal division of "total number of students" divided by desired number of "safety bubbles", instead it will be necessary to use machine learning to separate the students into "similarity" clusters.

For this, following Table 1 is built for every student that must have an experimental chemistry class:

From Table 1, we can see that Student A and Student X share 3 Lectures (A, B, C) therefore, however we would still need to prepare the data in a machine learning friendly format. This is done by graphing the students in a way, where interactions are marked as binary options (Class N has been removed for simplicity of table). Using machine learning, and Python a quick method can be implemented free of charge to cluster the students in accordance to the following definition:

"Clustering techniques apply when there is no class to be predicted but rather when the instances are to be divided into natural groups." [6].

For our study, we simplified the problem, and used an existing famous dataset in Data Science called "Zachary's Karate Club dataset", where a given karate club, has an administrator "John A" and an instructor "Mr. Hi" a conflict arises between them and causes the students to be split into two groups [7]. However, we will focus on the methodology of establishing a relationship within a group (Table 2).

In the Zachary Karate club example, the true division of the students was marked by Fig. 1.

Using Python and a very well-known K-Means clustering, we can obtain several solutions for any number of nodes and any number of clusters (Fig. 2).

Table 1 Sample table of student/lecture relationship.

Name	Class 1	Class 2	Class 3	Class …	Class N
Student A	Lecture A	Lecture B	Lecture C	…	Lecture E
Student B	Lecture C	Lecture A	Lecture F	…	Lecture H
Student C	Lecture D	Lecture G	Lecture W	…	Lecture L
Student X	Lecture H	Lecture C	Lecture A	…	Lecture B

Table 2 Student interactions derived from Table 1, whereas if Student A and Student B share a class; a 1 would be assigned to both Student A, Student B and Student B Student A relationship, if they do not share a class, then a 0 will be assigned.

Student	Student A	Student B	Student C	Student …	Student X
Student A	1	1	1	…	1
Student B	1	1	0	…	1
Student C	1	0	1	…	0
Student X	1	1	0	…	1
Student …	…	…	…	…	…

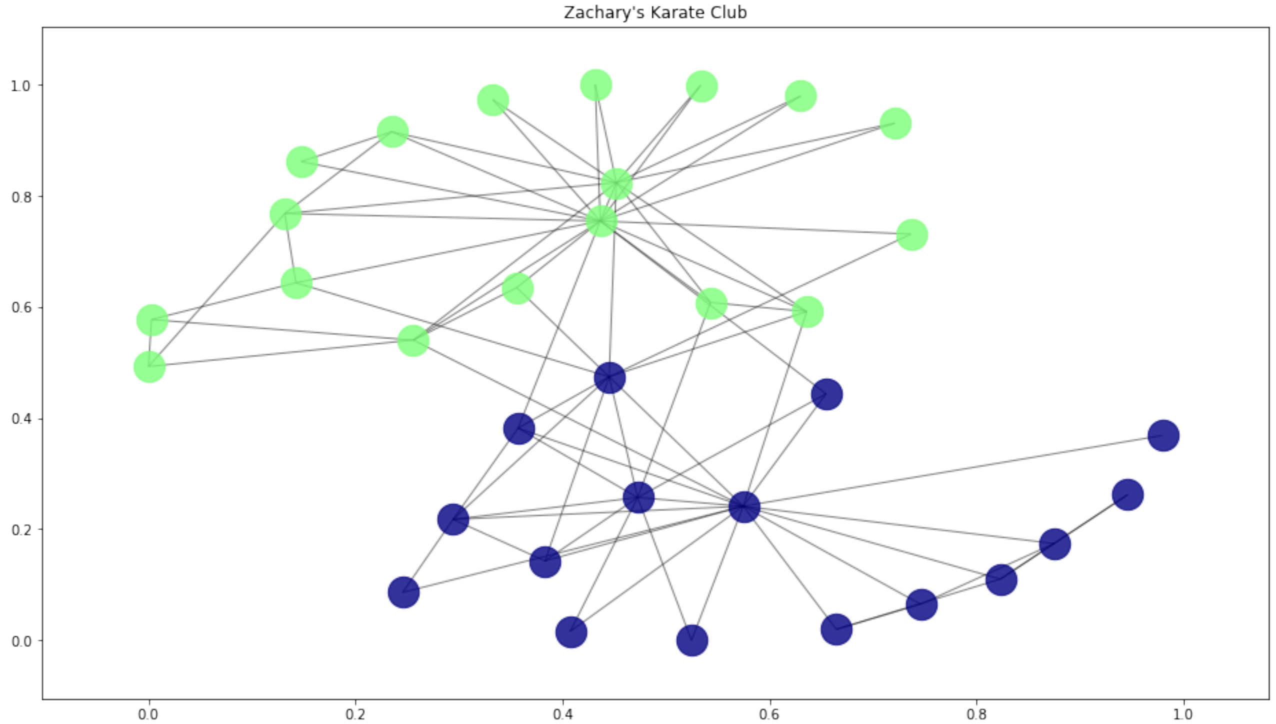


Fig. 2 True division of the Zachary Karate Club, where the nodes are students and they are colored according to their John A, "Mr. Hi" preference.

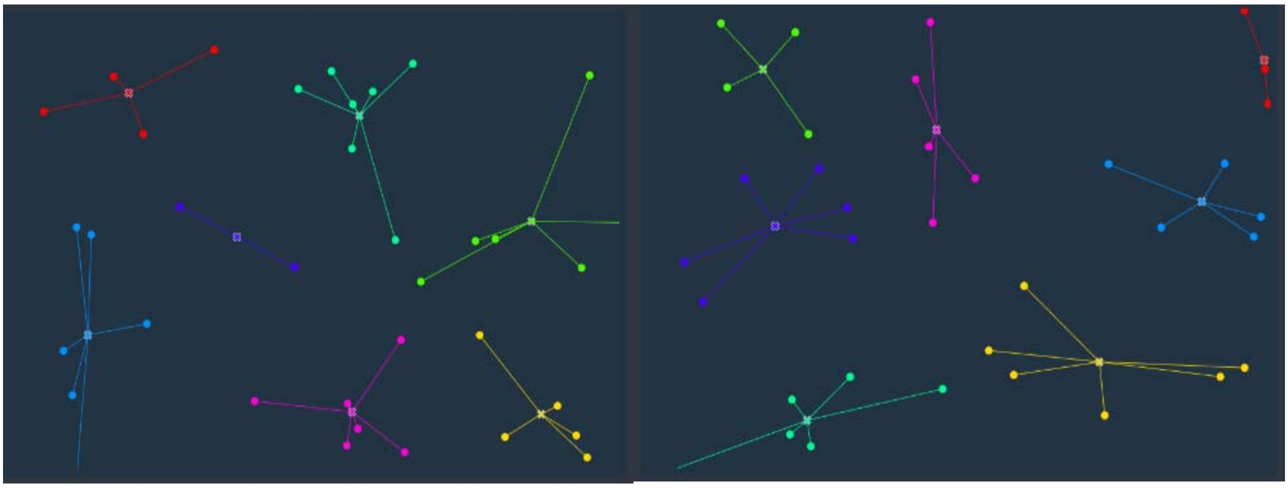


Fig. 3 Two possible solutions for Sample K-Means clustering for 36 nodes and 7 clusters (Source: github.com/nitoyon/tech.nitoyon.com).

3.2 Determination of the Number of Clusters

The next problem is determining how many clusters we should have, as the options for our example data set could range from 1 cluster of 36 students to 36 clusters of 1 student (Fig. 4). This becomes a problem in 2d geometry, given the area of the laboratory, we can divide each lab into 2 m. (≈ 6 ft.) discrete segments, making sure that a 2 m. (≈ 6 ft.) social distancing is observed in accordance to the CDC guidelines:

"To practice social or physical distancing, stay at least 6 feet (about 2 arms' length) from other people who are not from your household in both indoor and outdoor spaces". [8].

According to the Stanford Manual for Laboratory design guidelines [9]:

The space between adjacent workstations and laboratory benches should be 5 ft. or greater to provide ease of access. In a teaching laboratory, the desired spacing is 6 ft. Bench spacing shall be considered and included in specifications and plans.

So, the problem becomes much simpler, since we know the distancing between workstations is 6 ft., it is only a case of applying the most efficient circle packaging, which is a hexagonal lattice. Thus, the generalization would be:

If the circles have radius *r*, then each pair of horizontal red lines is a distance *r* apart, and they are a distance *r* from the edges. Each pair of vertical blue lines is a distance $r\sqrt{r}$ apart, and they are still a distance *r* from the edges.

So if you want the triangular packing to have *m* circles in each column, and *n* columns, then the rectangle must be at least $(2m+1)\cdot r$ units tall and $(2+(n-1)\sqrt{3})$ units long (Fig. 3).

The distance between the red lines is 6 ft. (as per distance between workbenches) and the distance between blue lines is $d = \sqrt{((2r\ (\text{ft.}))^2-(6\ \text{ft.})^2)}$ where *r* is 6 ft. (as per social distancing) and d = 10.39 ft, this can be seen in a 3-d overlay (Fig. 5).

The maximum number of clusters then is easily obtained, as it corresponds to the number of circles that fit in the area. However, there could be a case where the number of students per bubble is higher than the practical number of students per experiment, e.g. a laboratory can hold 12 circles, but the social bubbles would need to be 7 students, thus making the situation impractical, in which case, the number of clusters for that class should be doubled to half the number of students per bubble, in which case a rotation parameter would be needed. So, Rotation A would be week 1, rotation B would be week 2, etc.

Then each student bubble would have a third identifier, e.g. "experimental Chemistry 1-bubble 2-Rotation XX", where XX would be the rotation needed.

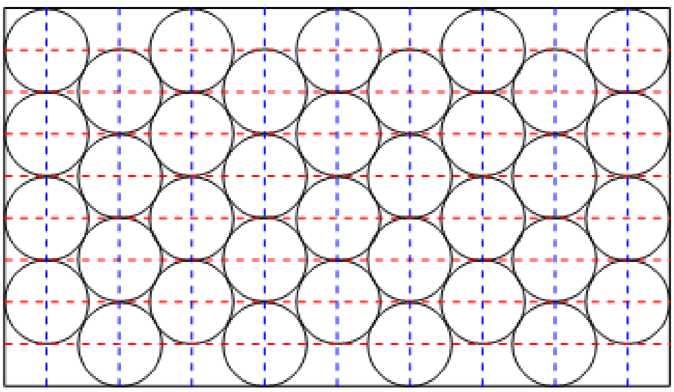


Fig. 4 Hexagonal lattice with social distancing radius.

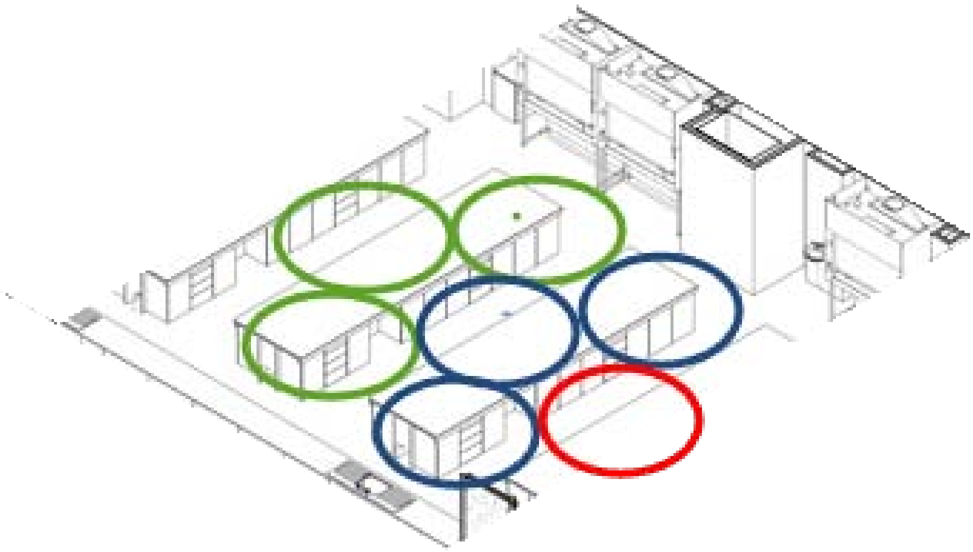


Fig. 5 Hexagonal latice overlayed on sample lab setup.

3.3 Material Preparation

The support staff is generally in charge of distributing the material required for all students, during the pandemic we need to ensure that they are in no point put at risk of infection, thus, all the necessary material would be placed in containers and in the workbench before the class, this is to minimize the need for the student to approach the support staff.

3.4 Questions/Quizzes/Communication with the Researcher/Professor

In addition to the normal material that a student is expected to bring to class, the following should be added:

(1) Headphones

(2) Laptop with external webcamera or Mobile Phone with Zoom™, Microsoft Teams ™ or Google Meetings™ installed, this depends on the preference of the university/professor.

(3) Mobile phone or laptop charger.

(4) Internet connection

Upon beginning the experiment, one student will oversee communications. This student, will keep an open Zoom/MS Teams/Google Meetings session with the professor, and will:

(a) Communicate all the questions doubts that his safety bubble has.

(b) Relay all the answers that the professor gives.

The use of headphones is necessary to reduce the amount of loud talking (for our study we equate singing to loud talking/yelling) in the laboratory, as this has been proven to increase the risk of transmission as per UK guideline on places of worship [10].

3.5 The Responsibilities of the Professor

The professor will need to sit in a socially distanced location within the laboratory, keeping an eye on both the students and the zoom session with each one of the safety bubbles.

In emergency situations, the professor will be expected to act accordingly, putting in second place social distancing.

In the case where the number of safety bubbles exceeds the number of socially distanced circles available in the laboratory, the professor will additionally have to:

(1) Set up his own experiment;

(2) Set up a suitable filming location within his workbench to allow his own experiment to be transmitted to the additional rotations established in the end of determination of the number of clusters section.

3.6 Safety of the Group

Each safety bubble will have one single representative, whose responsibility will be to "check" (either verbally or through a text message and prior to entering the lab) the health of each one of his safety bubble peers, should any of his peers within his safety bubble have any symptoms, the whole bubble would need to be absent from the laboratory for the recommended guidance time of 14 days [11] an added bonus is that the university will be better able to keep track of the possible CoVid-19 cases, and take the necessary approach either by contact tracing or similar method, assuming that every professor has a spreadsheet of the nodes that each student has access to, the flow of information should be easy.

4. Conclusions

During this essay, as expected, there was no single "silver bullet, all encompassing" solution to the problem of teaching experimental chemistry during these difficult times, this is because of the nature of the problem, experimental chemistry, because of its dangerous nature that cannot be taught only in a remotely "a la Cooking TV show" format. This is because the compounds and experiments are inherently dangerous, and a responsible knowledgeable figure must be present to take care of the students (Fig. 6). On the other hand, we cannot keep teaching experimental chemistry using the "old" method, as, again due to the nature of the lesson, the professor/researcher/supporting staff sometimes has to approach the students experiment and give his own insight/experience into the problem/question.

By no extent of the definition did we succeed in keeping the method of teaching experimental chemistry the same, nor was it ever the objective, nor would we achieve as much efficiency as the time-tested method we have enjoyed since Robert Boyle in 1661.

The biggest challenge we had was keeping the cost and use of resources low, as a developing country, Mexico amongst other hard-hit economies cannot afford to dress all their chemistry students in hazardous materials suits (Fig. 7). And the university would not have the resources to double up the amount of professor hours to double up the number of laboratories available. So, a fair compromise must be done, in which not all students are able to perform the experiment, but are able to experience it "live" with all the possibilities of an experiment going not according to plan (Figs. 8 and 9).

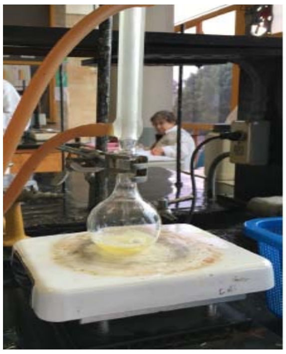


Fig. 6

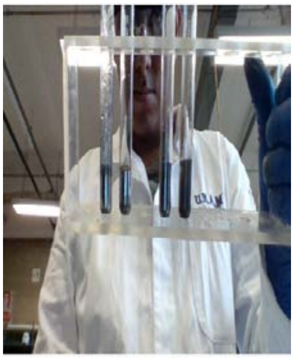


Fig. 7

Fig. 8

Fig. 9

The extra equipment needed for this solution is nothing that is not widely available, which is a laptop or mobile phone and headphones, with the ever-growing number of smartphones available c. 3.5 billion worldwide [12], the necessary equipment is statistically available in the pocket of any student. And the extra equipment necessary for the professor (an external Web Cam) is available at minimum cost.

From early on it was considered unsafe for our students to wear facemasks (surgical), as during an experiment, the concentration of any substance impregnated in the students mask might cause long term effects, and the addition of a typical facemask and safety goggles ends up in the student having foggy goggles, which will result in either the student removing the mask or removing the goggles periodically to clean them.

We think that more work can be done in optimizing the space, using more complex algorithms for different size radius so, we can take into account the fact that 3 students are not "exactly" in the centre of a safety bubble, but would alter the shape from a circle to a more complex figure. However, this is an area that we are currently researching.

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