Modelling of the Influence of the Peer Environment on the Prevention of Caries Development in Schoolchildren using a Hybrid Simulation Approach

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Keywords: Hybrid Simulation, Agent-based Simulation, Discrete Event Simulation, Dental Caries, Decision Support.

Abstract: Dental caries is a disease caused by medical and nonmedical factors. It can be prevented by taking conscious preventive action. In addition to the services provided by dentists and dental hygienists, awareness is very important in preventing the development of the disease. Awareness can be shaped, among other things, by the environment of peers. The aim of this paper is to use a hybrid simulation to investigate the impact of supportive, neutral, and non-supportive peer environments on strengthening or weakening the effectiveness of dental caries prevention in students of a sample primary school in southwestern Poland. Three experiments were carried out in which the effectiveness of preventive services varied. The effectiveness depended on the individual approach of the students to oral hygiene and dietary habits. Depending on the frequency of changing the closest peer environment, individual student attitudes change over time, which in turn affects the effectiveness of preventive services. Hybrid simulation, which combines discrete event simulation and agent-based simulation, used to model the effectiveness of caries prevention programs may be useful from the perspective of planning preventive care dedicated to children in schools.

1 INTRODUCTION

Dental caries has been recognized in the current century as a social disease that affects more than half of the world's population (WHO, 2017). It is caused by teeth demineralization due to a number of factors, including cariogenic bacteria and sugars (Featherstone, 2004). Although people of all ages suffer from it, the severity of the symptoms varies depending on the type of preventive measures taken, such as attending educational meetings, dental check-ups, fluoridation, and sealing of the teeth. The environment and the views of those around us also play an important role in caries prevention. A positive influence of an environmental group may result, for example, in greater attention to oral hygiene or less consumption of sugars, or, on the other hand, a negative influence may exacerbate poor hygiene and dietary habits. Depending on the environment, individual attitude may be formed in students.

Prevention from an early age is crucial and requires substantially fewer financial resources than caries treatment. Health policy planning is essential in the prevention of dental caries disease and is the focus of much reflection and discussion (Ramos-Gomez et al., 2020). In planning preventive care, it may be important to consider the environment for which care is dedicated. Depending on the region, for example, students may be more or less aware of health. They may be more concerned with hygiene or have better eating habits than in other regions. The main goal of health care is to ensure the health of the population by providing access to curative but also preventive services. Compared to treatment, prevention is much cheaper. However, to have the greatest effect in limiting the progression or occurrence of a disease, it must be introduced enough early. In the early years of life, parents and caregivers are responsible for the good oral health and hygiene habits of children. However, the number of children with dental caries shows that these individually

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undertaken measures are insufficient and do not produce the desired results. Therefore, it is very important to provide systemic support by conducting preventive programs in schools.

Simulation methods are playing an increasingly important role in supporting healthcare-related decision making (Kisliakovskii et al., 2017). Simulation methods used in health care can be classified in different ways; however, the most common methods are those from four subcategories: discrete event simulation (DES), agent-based simulation (ABS), system dynamics (SD), and Monte Carlo (MC) simulation (Brailsford et al., 2009). Simulation methods can be used in health care to support various types of decision. However, each of them, when used within the same problem, will potentially produce different results due to their different characteristics. Therefore, it is becoming increasingly popular to combine different methods in one approach. Models based on two or more simulation approaches such as DES, ABS or SD are called hybrid simulation. When combining simulation methods with analytical techniques, this is called the hybrid systems modelling approach (Powell and Mustafee, 2014). Applying a hybrid approach to healthcare can provide decision makers with a wider and better understanding than is possible with only one method (Zulkepli and Eldabi, 2015). Hybrid approaches emerged to take advantage of and overcome the limitations of individual methods. When combining DES and ABS, the DES method covers detailed modelling of the system, including flows and queues, but omits the possibility of modelling interactions between units. This feature, in turn, is an advantage of using ABS, but this method has the disadvantage of not having a queueing and flow concept (Abdelghany and Eltawil, 2014).

The aim of this paper is to use a hybrid simulation to investigate the impact of supportive, neutral, and non-supportive peer environments on strengthening or weakening the effectiveness of dental caries prevention in students of a sample primary school in southwestern Poland.

2 DATA AND METHODS

2.1 Study Design and Settings

The prevention of dental caries can take many different forms. From those provided individually in dental surgeries to group preventive services, usually held in schools. Few programs in southwest Poland provide, among other things, additional funding for services that are not funded by the National Health Fund. As part of the program: *Prevention of dental caries in students in primary schools in Wroclaw* (Nyczak, 2017), students in selected schools are provided with preventive actions such as dental check-up of students with determination of oral condition and educational, preventive, and therapeutic needs, stabilization of caries in primary teeth, sealing of permanent teeth, or treatment of "punctual" caries in permanent molars. This program is a multi-year undertaking, implemented in conjunction with the city's performance budget planning. Such programs are additional because, regional governments are responsible for ensuring that all students have access to preventive care (Journal of Laws of 2019, 1078). The National Health Fund finances this care, but the directors of individual institutions are responsible for providing it.

Education in Poland is divided into several stages, the first in primary school lasts 9 years: kindergarten and eighth grades. During education, students are provided with preventive services: check-ups, sealing of first molars, fluoridation, and education. It is assumed that in addition to these services, students exchange views on oral hygiene and oral health habits.

Awareness is very important in caries prevention. Depending on whether the student is aware of the negative impact of poor eating habits or the good impact of proper hygiene, he or she may support or inhibit the development of caries in the oral cavity. This awareness is influenced by many different factors, one of which is undoubtedly the closest environment. In addition to parents, children at school are surrounded by their classmates.

2.2 Data

Access to actual data describing the phenomenon of dental caries in schoolchildren in southwestern Poland is limited. In the present study, we used aggregated data showing the average number of primary teeth, permanent teeth, and the value of the dmft and DMFT indicators (dmft: decayed, missing, and filled teeth) in children 6,7,10,12 and 15 years of age (Tables 1 and 2). The dmft indicator is commonly used in dentistry, the higher the index value, the more advanced the caries. The symbol dmft is used for primary teeth and the symbol DMFT for permanent teeth.

The effectiveness of the preventive services undertaken was based on reports from the available literature after consulting with an expert dentist.

Table 1: Number of primary and permanent teeth: average [avg] and standard deviation [sd] in children aged 6, 7, 10, 12, and 15 years. Source: (Olczak-Kowalczyk et al. 2021).

Years old	Primary teeth [avg ± sd]	Permanent teeth [avg ± sd]
6	17.64±1.82	4.25±2.59
7	14.83±2.85	8.89±2.87
10	3.88±3.77	19.65±4.03
12	0	25.59±2.94
15	0	27.83±0.79

Table 2: Indicators of dmft and DMFT: average [avg] and standard deviation [sd] in children aged 6, 7, 10, 12 and 15 years. Source: (Olczak-Kowalczyk et al. 2021).

Years old	dmft [avg ± sd]	DMFT [avg ± sd]
6	3.65±3.21	0.09±0.47
7	5.42±3.25	0.61±1.12
10	1.62±1.88	1.88±1.63
12	0	3.60±2.74
15	0	5.42±3.69

2.3 Methods

We have constructed a hybrid simulation DES-ABS model to investigate the impact of the environment on the effectiveness of dental caries prevention in students (Figure 1). Both DES and ABS are methods commonly used in healthcare.

The DES method is a useful method for studying complex and dynamic systems and is often used to flow modelling. It has been used in problems related to more than half of the diseases in the ICD-10 classification (Zhang 2018). For modelling, e.g., infectious diseases, the ABS method is particularly applicable (Tracy et al., 2018). It is a method in which special attention is paid to the interactions that occur between the individual components of the system, the so-called agents. Therefore, the combination of these two methods enables the flow modelling and taking into account the interactions that occur during the simulation between the different agents (Abdelghany et al., 2016).

The DES method was used to model the educational process in primary school along with preventive services provided such as dental check-ups, sealing of first molars, fluoridation, and education. An ABS method was used to model interactions between agents, who are students. The combination of these two methods allowed verifying the effect that contact with peers can have on increasing or decreasing the effectiveness of preventive services.

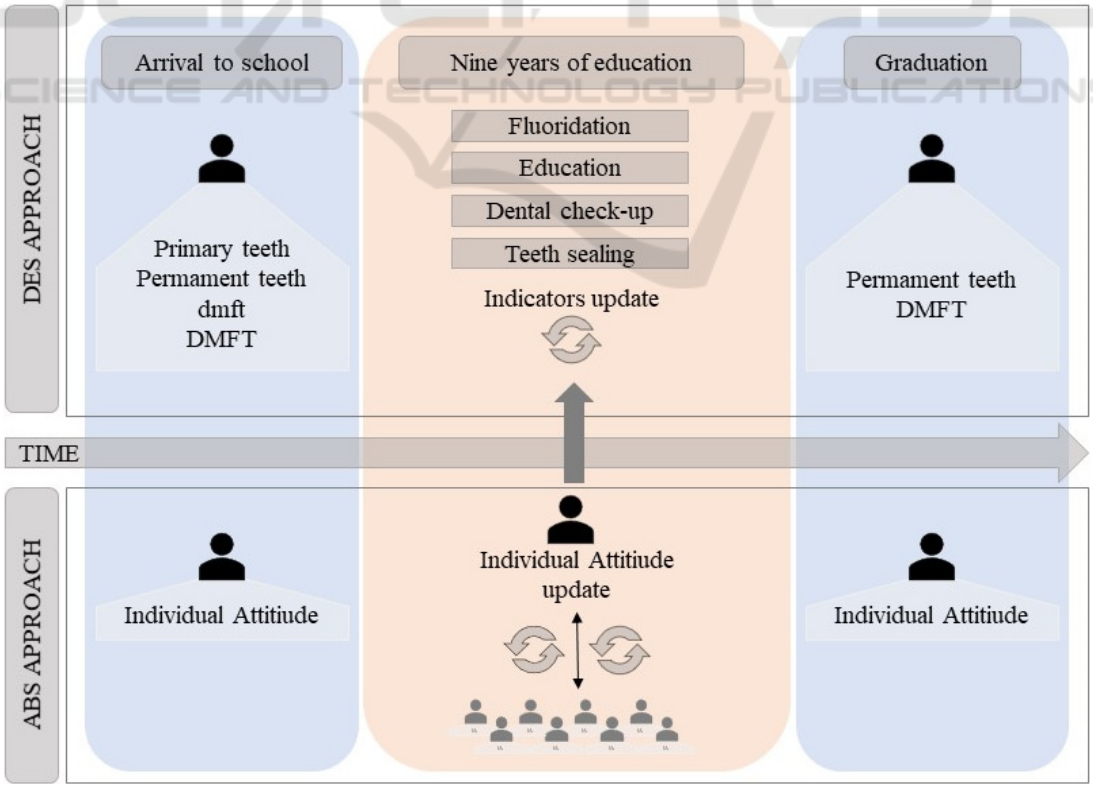

Figure 1: Hybrid simulation: overview of the DES-ABS model.

The DES part is responsible for simulating the growing process of children over the course of their primary schooling. Each student starts school with values for four basic attributes: primary and permanent teeth, dmft, and DMFT taken from real data. Then, preventive services are provided during their nine-year education. Indicators are updated once a year. Graduation students have a given number of permanent teeth and a DMFT indicator value.

The time and effectiveness of the measures taken influence the update of the indicators. Part of ABS is responsible for tracking students' attitudes toward oral health care. Each student, through contact with other students, can change his or her attitude towards taking care of health. Students change their closest environment at school by changing their classmates with whom they share their opinions about oral health. After any change in the environment, their individual attitude (IA) towards oral hygiene care, dietary habits, or overall attitude toward oral health may change. Depending on whether immediate peers have a negative, neutral, or positive IA, the effectiveness of preventive services may be decreased or increased.

3 SIMULATION MODEL

3.1 Overall Algorithm

The hybrid model was built in Arena by Rockwell Automation. Ten replications were conducted; one replication covered 6570 days, or 18 years. A warm-up period of half that time was assumed so that the school would be filled with students before statistics collection began. A classroom of 20 students was observed, and the effectiveness of preventive services was tracked over time without and after taking into account social influence.

The DES model with verification and validation is presented in detail in Hajłasz and Mielczarek (2022). The effectiveness of preventive services was developed with a dental expert based on reports in the literature. Effectiveness is understood as the percentage that accounts for the reduction in caries growth that would have occurred if these services had not been provided.

The ABS model assumes that each student can be assigned one of three attitudes toward oral hygiene: IA negative (-1), IA neutral (0) and IA positive (+1). At the beginning of the simulation, each student is assigned an IA value based on his or her oral health. To simulate the interactions between the students, a two-dimensional grid was constructed, which is a typical cellular automaton. Each field represents a space that can be occupied by a student. Students change their surroundings and, by extension, their neighbors. Figure 2 shows the initial example setup (0) of the students along with an example change (1). Each shaded grid corresponds to one student with an ID number of 1 to 20. Each time, each student randomly shifts to one of eight adjacent grid squares. Then the IA of neighboring students are checked, and a given student can change its IA.

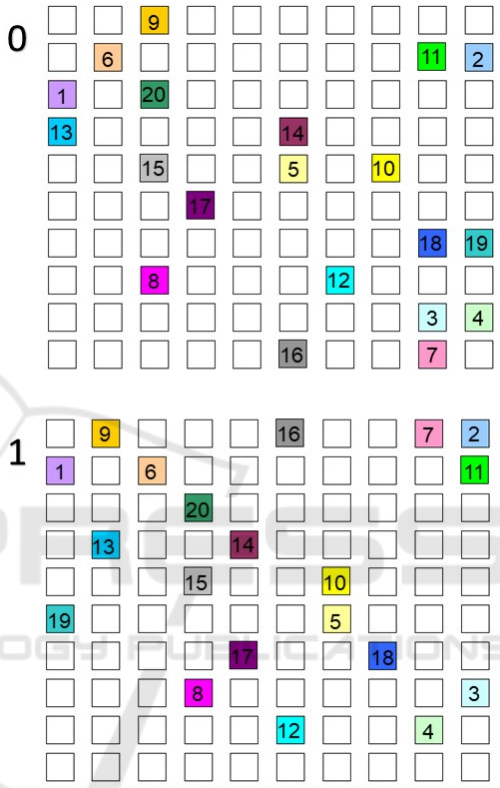

Figure 2: The example of the students' closest environment in the initial state and one example change.

Each student exchanges his or her views with different classmates. The attitudes of classmates can change a given student's attitude, so his or her IA can change depending on three conditions. If the summative IA of the closest surrounding students is less than a given student's IA, then there is a 50% chance that a given student, if he or she has a positive or neutral IA, will change it to a negative IA. If, on the other hand, the summative IA of the clostest surrounding students is greater than a given student's IA, then there is a 50% chance that a given student, if they have a negative or neutral IA, will change it to positive. If the summative impact of the closest surrounding students is the same as a given student's IA then nothing changes. There is also no chance of changing the IA from negative or positive to neutral.

The closest environment is understood as the students occupying cells immediately adjacent to a given student cell in the grid.

The IA of students is read at the time of updating the dmft and DMFT indicators in the DES model, i.e., at the end of the school year. Depending on whether a student's IA is negative, neutral, or positive, this changes the baseline effectiveness value of the preventive services undertaken.

The main output measure is the average number of pupils having a certain sum of dmft and DMFT at the end of each school year. Depending on this sum, each student is classified into one of three dental caries states (DCS): good, moderate, or bad (Table 3). Over time, the values of the dmft and DMFT indicators change, which may cause a change in the DCS class. These classes were defined and named by the authors.

Table 3: Three states of dental caries state (DCS) depending on the sum of dmft and DMFT in each pupil.

DCS	dmft + DMFT
Good	0
Moderate	1-3
Bad	4 and more

3.2 Simulation Experiments

Three simulation experiments were conducted (Table 4). In the first experiment, it was assumed that students are provided with regular fluoridation, dental check-ups, sealing of first molars, and education, and the effectiveness of the services is expressed as a percentage and generated from triangular distributions.

Table 4: Plan of the experiments.

Scenario	Effectiveness of caries prevention
1	The same applies to each pupil
2	Variations by IA updated annually
3	Variations by IA updated twice a year

The parameters of the distributions in the first experiment are independent of the IA value of a given student, that is, they take values corresponding to neutral IA (Table 5).

In the second and third experiments, IA is affected by contact with closest peers. In the second experiment, students change their environment once a year, while in the third experiment, they change their environment twice a year. Initial IA values are generated depending on the initial value of DCS indices, i.e., how many primary and permanent teeth with dental caries a given student has. If he or she has all healthy teeth, then the initial IA is +1, if he or she has 0 to 3 teeth with caries, then the IA is 0, if he or she has more than 3 teeth with caries, then the IA is-1.

Table 5: Effectiveness of preventive services depending on a student IA: most frequent value, and range of triangular distribution.

IA	Primary teeth (%)	Permanent teeth (%)
-1	23 (17,27)	77 (71,81)
0	26 (20,30)	85 (79,90)
1	29 (23,33)	93 (87,97)

3.3 Simulation Results

The DES model was able to track changes in the average number of students with a given DCS indicator. On the contrary, the ABS model provided information to the DES model about how the level of effectiveness of preventive services varied by student IA. Figures 3 and 4 show how the average number of students with a given IA evolved depending on whether the students changed their closest environment once a year (scenario 2), or twice a year (scenario 3).

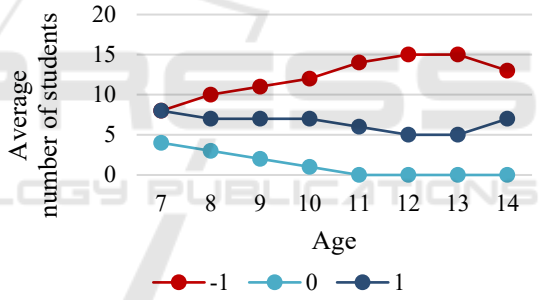

Figure 3: Average number of students with one of the three IAs (-1,0,1) at each age for which the effectiveness of preventive services was updated, assuming that students change their closest environment once a year.

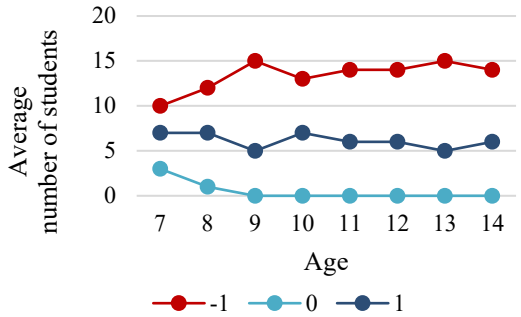

Figure 4: Average number of students with one of the three IAs (-1,0,1) at each age for which the effectiveness of preventive services was updated, assuming that students change their closest environment twice a year.

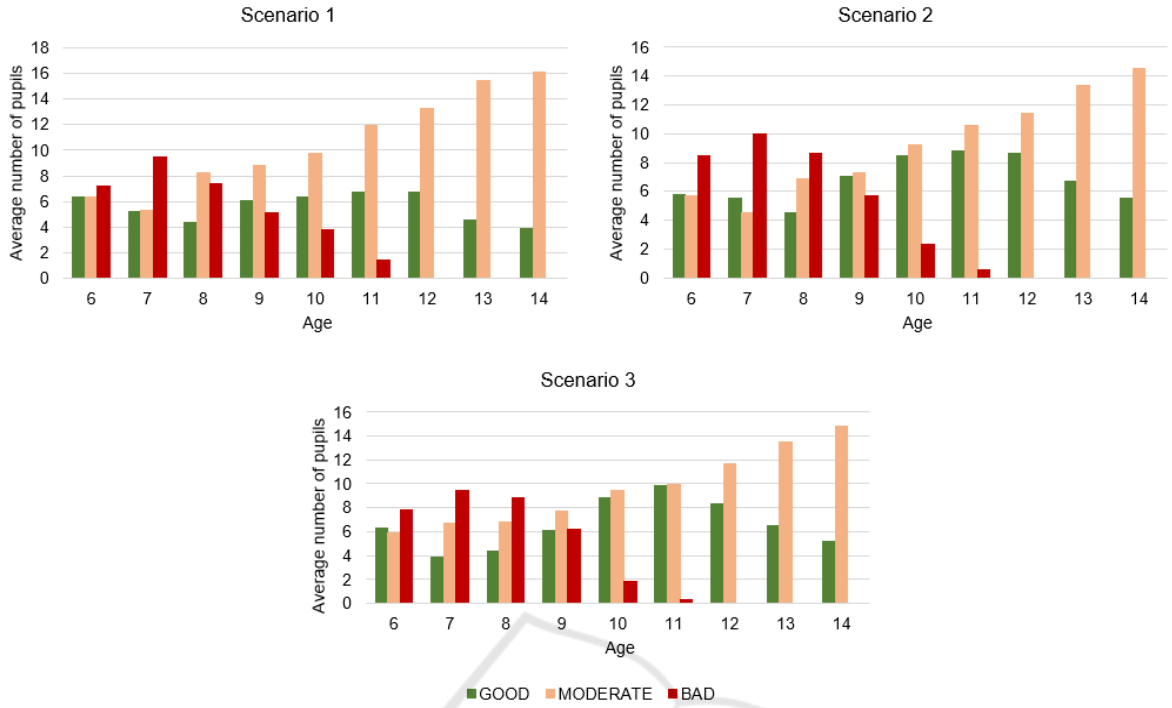

Figure 5: Comparison of the average number of the same group of 20 students with a given DCS class in all experiments conducted; results of 10 replications.

Table 6: Average number of students with one of the three DCS classes in each of the three experiments. Average of 10 replications for 20 students.

DCS	Scenario	6	7	8	9	10	11	12	13	14
Good	1	6.4	5.2	4.4	6.1	6.4	6.7	6.7	4.6	3.9
	2	5.8	5.5	4.5	7	8.5	8.8	8.6	6.7	5.5
	3	6.3	3.9	4.4	6.1	8.8	9.8	8.3	6.5	5.2
Moderate	1	6.4	5.3	8.2	8.8	9.8	12	13	15	16
	2	5.7	4.5	6.9	7.3	9.2	10.6	11.4	13.3	14.5
	3	5.9	6.7	6.8	7.7	9.4	9.9	11.7	13.5	14.8
Bad	1	7.2	9.5	7.4	5.1	3.8	1.4	0	0	0
	2	8.5	10	8.6	5.7	2.3	0.6	0	0	0
	3	7.8	9.4	8.8	6.2	1.8	0.3	0	0	0

In the first scenario, the average group of children with good and moderate DCS at graduation was 3.9 and 16 students, respectively (Figure 5). In the experiments that included IA, whether the students changed their environment twice a year or once, the results were similar for these experiments. With good DCS they graduated an average of 5.5, with moderate DCS 14.5 in the second experiment. In the third, 5.2 and 14.8, respectively (Table 6).

Students may change their IA several times during their primary education, which impacts the effectiveness of services, which translates into the number of students with a given DCS.

4 DISCUSSION

Caries disease is a disease that is the result of many factors. It is also a disease that is relatively easy to prevent. This is confirmed by the literature reports and conducted studies. Preventive services regularly provided to schoolchildren can significantly reduce

the problem of caries. The effectiveness of preventive measures, in addition to the effectiveness of medical procedures, is influenced by individual attitudes and behaviour of students. The present study considers individual attitude of students, which is randomly shaped by a student's interactions with his or her closest peers within a single classroom.

If the majority of students have the IA equal to 1, which corresponds to positive attitude, there is a much greater chance that this group will convince children with the IA equal to 0 or -1 (neutral and negative) that hygiene and healthy habits are worth it, which in turn may results in reduced caries.
If, on the other hand, the majority of children had the IA equal to -1, this could lead to a deterioration in the health of the students in the class. much greater chance that this group will convince children with the IA equal to 0 or -1 (neutral and negative) that hygiene and healthy habits are worth it, which in turn may results in reduced caries. If, on the other hand, the majority of children had the IA equal to -1, this could lead to a deterioration in the health of the students in the class.

The hybrid simulation that combines DES and ABS approaches allows testing many different scenarios of the effectiveness of preventive services together with the interactions that occur between students at the school. The DES simulation alone cannot verify this impact, and it is believed that in the context of dental caries prevention, awareness of the importance of good hygiene and diet is important and may or may not support the effectiveness of other measures such as fluoridation, sealants, check-ups, or education.

5 CONCLUSIONS

This study identified the usefulness of hybrid simulation to investigate the impact of supportive, neutral, and nonsupportive environments on strengthening or weakening the effectiveness of dental caries prevention in students of a sample primary school in southwestern Poland.

The main strength of the suggested approach lies in the ability to comprehensively follow the development of dental caries in students in different scenarios, taking into account not only the effectiveness of services, but also individual social interactions. The primary limitation of the present study is the limited access to detailed source data.

Therefore, further research primarily is planned to acquire detailed source data. Additionally, school surveys are planned to verify the IA in students according to the region of residence of the students, among others. It is also planned to conduct experiments taking into account more classers or schools and the students' region of residence or other demographic factors that may influence the formation of individual student attitudes toward oral hygiene, broadly defined.

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