ToothPIC: An Interactive Application for Teaching Oral Anatomy

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Abstract—This paper describes the development and evaluation of an interactive educational program, *Tooth Placement and Identification Coach* (*ToothPIC*). The program uses a game-based learning paradigm and 3D visualization techniques to allow first year dentistry and hygiene students to get familiar with dental anatomy. It provides an interactive and stimulating learning tool for acquiring basic dental skills outside of the classroom. Specifically, it uses interactive 3D graphics to teach students to identify, name, number, align, and orient teeth into their proper location in the dental arch. *ToothPIC* incorporates elements of a game to make learning attractive for the student. In the process, the student learns not only about the 3D features of each tooth but also about the proper placement of the tooth relative to the gingiva and other teeth. *ToothPIC* has two modules: Module 1 includes 32 permanent upper and lower teeth that are to be identified and placed into the surrounding gingiva. Module 2 only shows the individual teeth, one at a time, to be identified (similar to a "flash-card"). The evaluation results of *ToothPIC* indicate that students strongly agree that program meets its goals of self-training and self-evaluation, actively involves the students in learning and is a useful supplement to laboratory practices and lectures.

Index Terms—Dentistry education, dental anatomy, game-based learning, interactive 3D training

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1 INTRODUCTION

WHILE the landscape of Higher Education continues to shift as institutions cope with increased public scrutiny and seek to realize full promise of technology, perhaps no discipline has seen more dramatic changes than dentistry. The primary drivers of these changes are the shortage of instructors, budget constraints and the need to markedly alter and enhance the educational process [1], [2]. To help address some of these problems, an educational program, *ToothPIC* (*Tooth Placement and Identification Coach*), was developed that uses gaming and 3D computer graphics as a learning tool. It uses innovative educational technology to improve training basic skills needed by dental and related professionals. The 3D graphics enables the students to self-train in identifying, naming, numbering, and alignment of teeth in the upper and lower dental arch.

ToothPIC builds on our experience in developing *Periosim*, a simulator for dental education that uses 3D graphics in combination with a haptic device [3] to train dentistry students in using various dentistry instruments as well as to assess their skills [4]. Given our experience with haptics, *ToothPIC* was designed so that if students have access to a haptic device they can use it with the program to increase the realism of the experience and simplify the user interface. In the absence of a haptic device, the student can use a mouse and a graphical interface to achieve the same functionality.

The effectiveness of educational software for dental education has been examined by many studies [5], [6], [7], [8]. They indicate that students are positively inclined towards computer-assisted

learning and find educational software enjoyable and easy to use [9]. More broadly, the meta-analysis report and other research syntheses indicate that simulation technology is highly effective for education and competence assessment that can lead to health care improvement [10]. Another aspect relevant to *ToothPIC* is game-based learning [11] – learning through a computer application that delivers specified training objectives and has the characteristics of a computer game. Game-based learning is gaining popularity in recent years, effectively increasing users' interest in learning [12].

Knowledge of tooth identification is critical for new dental and dental hygiene students. The usual methods for learning these skills consist of lectures, instructor demonstrations and laboratory training. Laboratory exercises comprise of line drawings and carving teeth out of wax blocks [13]. These methods require much instructor/student interaction, have to take place in an educational laboratory under rigid schedules, and force learning at a fixed pace. Computer applications like 3D Tooth Atlas [14] and Morpho-Dent [15] have been developed recently to help resolve some of these problems. These applications allow observation of teeth morphology in 3D and user may also interact with these programs in selecting a particular tooth, observing particular features and rotating the selected tooth. The innovate aspect of *ToothPIC* as compared to these educational programs is the combination of a challenge of a game and education. *ToothPIC* not only allows the user to rotate teeth graphic models in 3D and view them from all sides, it also challenges the user to place the selected tooth in its right 3D location and orientation in the arch. The challenge of a game stimulates students' motivation for learning and actively keeps them involved [16]. Active instructional processes in turn result in more effective learning [17]. Specifically *ToothPIC* is designed to help students' self-training and self-evaluation in:

- Basic knowledge of tooth anatomy.
- Rapid recognition of the name and universal number of each tooth.
- The spatial location of each tooth in the upper and lower arches, as well as the ability to manipulate each tooth and place it into its proper location.

As an educational game, *ToothPIC* is designed to provide the following advantages:

- *Self-paced learning*: Students prefer different paces of learning. *ToothPIC* allows the students to learn at the pace with which they are more comfortable, adjusting it each time.
- *Self-training*: Students can learn independently of the instructor at their preferred time for as long as they want. The aim is not to eliminate lectures and laboratory practices but to reduce the time spent in them and make them more effective.
- *Self-evaluation and immediate feedback*: *ToothPIC* evaluates the student's knowledge about the name, corresponding universal number of individual tooth and its correct alignment in the arch. It then shows the correct answers and keeps track of how accurately the student is able to answer the questions.
- *Engagement*: The program makes learning more entertaining and holds student's interest, thus creating an active learning environment for the student.

Evaluation results by students indicate that *ToothPIC* successfully achieves its goals. Students strongly agree that the program allows for self-training with the average score of 6.82 out of 7 as mentioned (Table 2). Students also highly rate the program on assessing the skill of teeth identification and placement, giving it an average score of 6.82 out of 7. Finally, on engagement, the students rate the program with a score of 6.5 out of 7, again demonstrating that this goal has been largely met.

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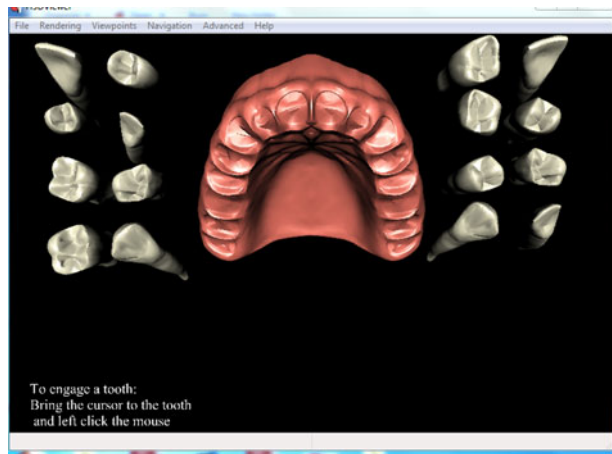
Fig. 1. Empty upper arch with 16 randomized upper teeth randomly located on either side of the dental arch.

2 MATERIALS AND METHODS

ToothPIC is developed using open source software (2.2). The program is composed of two distinct modules. Module 1 includes 32 permanent upper and lower teeth that are to be identified and placed into the surrounding gingiva. Module 2 only shows the individual teeth, one at a time, to be identified (similar to a "flash-card").

Module 1 uses 3D virtual models of permanent teeth and an empty arch. It requires the students to pick a tooth from a group of randomized teeth, in a virtual 3D scene, place it in its correct location and orientation on the empty arch, as well as name and number the selected tooth. The students can view the selected tooth as well as the entire graphic scene from various views. Once the students place the tooth at what they perceive as its right location and orientation, they can check their answer and proceed with the remaining teeth that still need to be placed on the arch. Module 1 is further divided into two parts: one is for the upper teeth and the other for the lower teeth (2.3).

2.1 Graphical Models

The program involves using 3D, virtual reality(VR) graphics. We have used two sets of 3D upper and lower arch models along with sixteen upper and sixteen lower permanent teeth obtained from Viewpoint Corp (Viewpoint Corporation Digimation, St. Rose, LA [18]). One set contains teeth crowns only whereas the other has both crowns with associated roots. These models are defined such that each tooth model can be separated from the arch and can be treated as an independent identity.

2.2 Software Components

ToothPIC is programmed using H3DAPI [19], an open source software development platform, that uses standard OpenGL [20] and X3D [21] to handle 3D graphics. Although this application can be developed using OpenGL directly without using H3DAPI, we required H3DAPI because the program is designed so that if students have access to a haptic device they can run the same program with that device [3]. This allows students to feel the teeth and interact with the model in a more natural way. The main program is written in open source Python programming language [22]. The implementation of matrix operations requires the NumPy library of Python [23]. To add graphical user interface (GUI), Python binding to the open source TkGUI toolkit, Tkinter [24], was used. 3D graphical models of teeth and gingiva are described in X3D. X3D is the ISO standard XML-based file format for representing 3D computer graphics, the successor to the Virtual Reality Modeling Language (VRML).
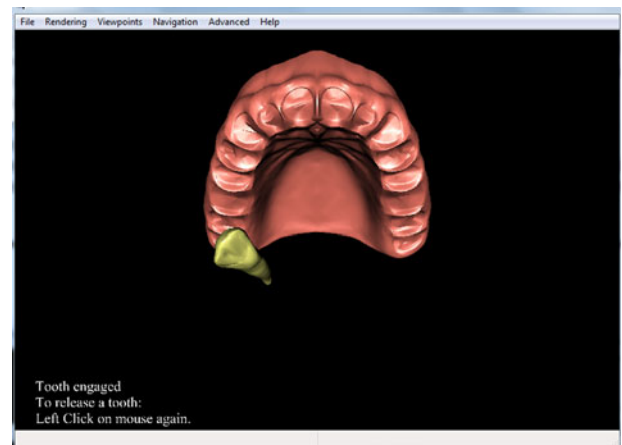

Fig. 2. An engaged tooth.

2.3 *ToothPIC* Overview (Module I)

ToothPIC (Module 1) has been divided into two components:

- Sixteen permanent upper teeth (including roots) and an upper arch (Fig. 1).
- Sixteen permanent lower teeth (including roots) and a lower arch.

The program functionality is the same for each component. Dealing with the upper and lower arches separately allows students to learn in a modular manner and concentrate on only a subset of all teeth. It also makes the graphics clearer and facilitates the handling of sixteen separate, upper or lower permanent teeth along with their respective arches.

We tested *ToothPIC* during its development by having various dentistry and dental hygienist faculty use it. Their suggestions for improvement proved invaluable and are incorporated into the current version. These suggestions included ideas to improve the user interface (Section 2.4.2) by using icons for the buttons which correspond to their functionality, short-cut keys for various views important for dental observations and changing the color of the engaged and disengaged tooth (explained in Section 2.4).

2.4 *ToothPIC* Functionality

The program requires the student to select a tooth from a group of randomized teeth, place it in its correct location and orientation on the empty arch, as well as name and number the selected tooth.

2.4.1 Graphics Window

Fig. 1 shows all the teeth and an edentulous arch. Students can select and engage a tooth by moving the cursor over it and depressing the left mouse button. As long as the button remains depressed, a tooth follows the movement of the mouse and therefore may be moved freely into any position in the virtual 3D environment. Using the mouse wheel moves the tooth in or out of the screen (z-axis). Engaging the tooth turns it from an off-white natural color to yellow, while simultaneously making the other 15 teeth disappear. As long as the tooth remains engaged, it can be moved, but not rotated (Fig. 2). Releasing the left mouse button disengages the tooth and returns it to its natural color. Double clicking on the left mouse button turns the selected tooth blue and disengages it (Fig. 3). Depression of the right mouse button while the tooth remains blue permits rotation of the tooth in any direction using the mouse movements.

2.4.2 User Interface

The user interface (Fig. 4) has the information necessary to operate the program. With it the students can rotate each tooth into its
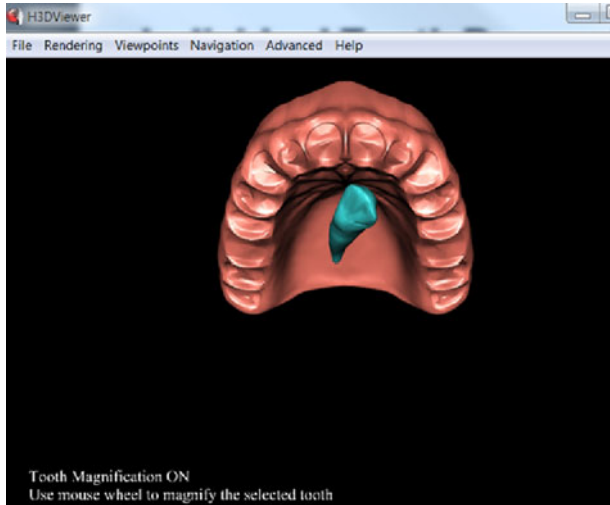
Fig. 3. A disengaged tooth.

proper 3D arch orientation while learning its name and universal number. The tooth location can be adjusted as needed to make a final determination on whether it has been properly placed. When desired, the program can show the correct placement and alignment of a tooth by pressing the control panel (c) button. Other teeth

can be selected one by one from the random grouping and properly placed in the arch until all available teeth are used (Fig. 1).

The user interface includes the following components:

- *Tooth Identification Block (a)*: prompts students to select the name of the tooth and asks them to enter its corresponding universal number. Users can immediately check their answers either before or after aligning the tooth in the arch. The correct name and number of the selected tooth is displayed on the control panel.
- *Name and Number Block (b)*: displays the correct name and number of a selected tooth after a user has entered his/her answer. It helps students to see and learn the name and number of an engaged tooth while trying to align it on the model.
- *Button (c)*: The "CORRECT alignment of tooth" button moves the tooth to the proper location and orientation. After users have set their selected tooth in what they believe is the correct position on the arch, they can verify the result by clicking on this button. It moves the tooth to its correct location and alignment.
- *Button (d)*: The "View all non-visible teeth" button permits the engagement of another tooth by restoring visibility of the previously hidden array.
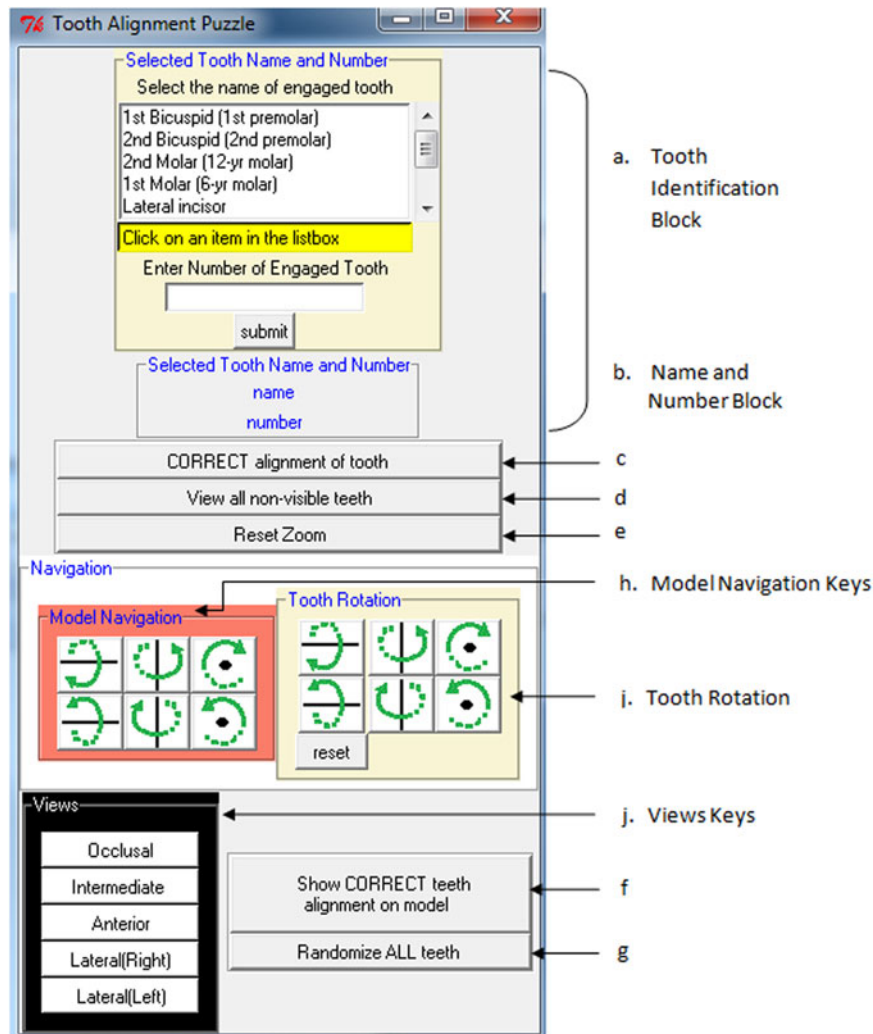- *Button (e)*: The "Reset Zoom" returns the model to its original size.
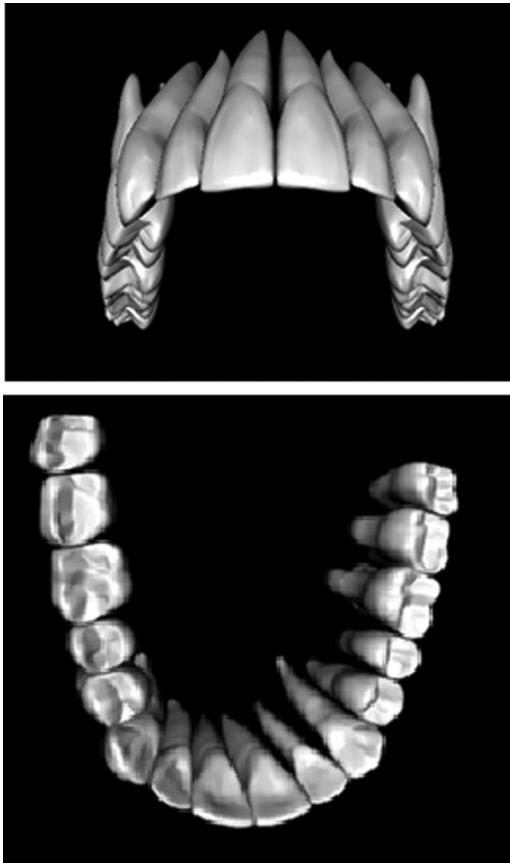

Fig. 4. User Interface.

Fig. 5. Two views of upper and lower reference models of the dental arch used for observing proper tooth alignment.

- *Button (f)*: The "Show CORRECT teeth alignment on model" will place all of the teeth on the arch into their correct orientation and alignment on the model arch.
- *Button (g)*: The "Randomize ALL teeth" button may be used if users want to re-randomize all the teeth and practice again.
- *"Model Navigation" keys (h)*: may be used to view and rotate the dental arch model from different angles. The arrow on each key shows the axis and direction of rotation. The keys rotate all the graphical objects with respect to the global reference frame.
- *Engaged "tooth rotation" keys (i)*: do the same as above, but just for the selected tooth. Pressing this key rotates the selected tooth in its body reference frame. The reset key may be used to bring the tooth back to its original orientation.
- *"Views" buttons (j)*: Activating one of these buttons permits quick use of five standard views of the arch. This saves time in aligning an engaged tooth and helps users learn the names of different views.

2.5 Complete Teeth Model with Roots

The complete teeth model window (Fig. 5) can be used as a reference for the location and alignment of individual teeth while using *ToothPIC*. It shows the 3D model of all teeth with roots in an upper or lower arch depending upon which arch the user is working. The user may rotate the model to view the teeth alignment from different angles.

3 RESULTS

In order to get feedback from prospective users of the program, students were invited to use and evaluate it using a questionnaire with respect to 5 design goals:

TABLE 1
Preliminary Evaluation Results

Category	Area	Mean Score
ROS		1 (Not Real) - 7 (Very Real)
	Teeth anatomy	5.75
	Teeth color	6
	Gingiva	5.25
IL		1 (Not Useful) - 7 (Very Useful)
	Overall	5.5
ALG		1 (Not at All) - 7 (Definitely)
	Differences in teeth anatomy	5.5
	Teeth alignment in the arch	5.25
	Teeth name and number	6
	Self-training	5.75
	Active involvement in learning	6.5
	Assess the skill of teeth identification and placement	5.5
DUP		1 (Easy to Use) - 7 (Hard to Use)
	Overall	4.19
PT		1 (Strongly Disagree) - 7 (Strongly Agree)
	Self-instruction before lectures and lab. experience	6
	Substitute for instructors	3
	Supplement for instructors' lectures	5
	Substitute for lab. practice	3.25
	Supplement for lab. practice	5.75
	Refresher anytime in curriculum	6

1) Realism of oral structures (ROS)
2) Usefulness of instructional layout (IL)
3) Achievement of learning goals (ALG)
4) Difficulty of use of the program (DUP)
5) Program potential for teaching (PT)

The questionnaire contained a total of 39 questions, each of which rated specific features of the program.

First, a preliminary evaluation of the program was performed by four dental hygiene students. The results of this preliminary evaluation are shown in Table 1.

While the sample size for evaluating the program was very small, several modifications were made based on the student survey and instructors comments. It was at their suggestion that we incorporated rotating teeth with the mouse as a more natural way to rotate objects than just using the control panel. It was also because of instructors' and students' comments that we added roots to the tooth models, since roots play an important role in tooth identification.

After incorporating these improvements, *ToothPIC* was again evaluated by 11 dental students using the same questionnaire as used for preliminary evaluation. Table 2 presents the results of this evaluation. The evaluation results of final improved version of *ToothPIC* show significant improvement over the preliminary evaluation.

The evaluation scores for the potential of *ToothPIC* suggest that such a take-home program would provide a valuable supplement to laboratory sessions with physical models and instructor lectures, possibly replace some lectures and laboratory practices, as well as serve as a refresher at any time during the course of study. Students did not consider this program as a substitute for lectures and laboratory practices, but felt it could reduce the lecture time on the subject. The obtained results indicate that the images used were quite realistic and the instructions given by the program were reasonably clear and well presented. Students agreed that the program achieves its educational goals of self-learning, self-evaluation and involving users actively in the learning process. The difficulty

TABLE 2
Evaluation Results

Category	Area	Mean Score
ROS		1 (Not Real) - 7 (Very Real)
	Teeth anatomy	6
	Teeth color	5.82
	Gingiva	6.18
	Roots' shape	6.54
IL		1 (Not Useful) - 7 (Very Useful)
	Overall	6.75
ALG		1 (Not at All) - 7 (Definitely)
	Differences in teeth anatomy	6.46
	Teeth alignment in the arches	6.54
	Teeth name and number	6.73
	Self-training	6.82
	Active involvement in learning	6.5
	Assess the skill of teeth identification and placement	6.82
DUP		1 (Easy to Use) - 7 (Hard to Use)
	Overall	2.67
PT		1 (Strongly Disagree) - 7 (Strongly Agree)
	Self-instruction before lectures and lab. experience	6.36
	Substitute for instructors	4.18
	Supplement for instructors' lectures	5.91
	Substitute for lab. practice	5
	Supplement for lab. practice	6.73
	Refresher anytime in curriculum	6.73

Fig. 6. ToothPIC Module 2.

to use program (DUP) has reduced greatly by introducing teeth rotation with mouse. In addition to the asked questions most of the students have commented that *ToothPIC* is easy to use and is very useful for learning teeth anatomy.

4   DISCUSSION

ToothPIC is a self-study, ancillary educational tool to teach basic tooth recognition and alignment to novice students while making the program highly interactive and easy to use. We designed it for use outside of the classroom and not as a replacement for instructors. This program covers the following levels of Bloom's taxonomy [25]:

- *Remembering*: The program helps students to remember the name and universal numbers of teeth as well as the names of different angles of observing the teeth.
- *Understanding*: Students learn to place adult teeth in their right location on the edentulous arch.
- *Analysis*: Students learn to distinguish between different adult teeth.

The program is designed in a way that if students have access to a haptic device they can run the same program with a haptic device [3]. This allows students to feel the teeth and interact with the model in a more natural way.

ToothPIC is extended with a second module (Fig. 6) where students are presented with one tooth at a time; the student can rotate the tooth to see it from every angle. The student is then asked to identify the arch, quadrant, name and universal number of the presented tooth. Students can terminate the program at any time and upon termination of the program the student is presented with the score of how many of the entered answers are correct.

The work presented in this paper may be used with different graphics models for various other educational purposes where 3D visualization and manipulation of graphic structures is required.
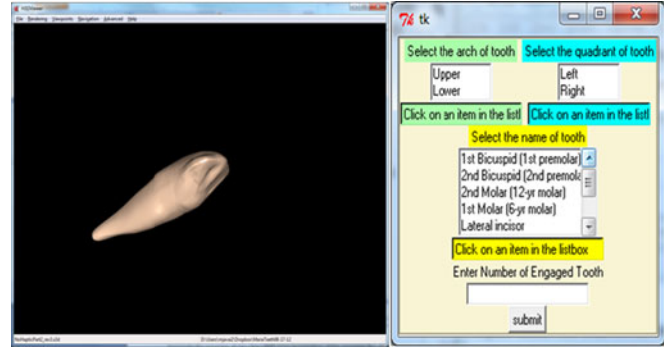
This may ranges from education in K-12 to professional usage. At K-12 a version of this software may be used for teaching astronomy, atomic structure and human anatomy. These areas require recognizing various elements and also require students to have knowledge of the placement of each element in an overall 3D environment. In human anatomy, for example, students should know where each organ belongs or where a particular bone belongs in the human skeleton. It has great potential to be used in teaching chemistry where molecular 3D modeling is required, helping students visualize the 3D structures [26]. Similarly, this program, may be used in teaching and evaluating of medical education particularly anatomy and physiology [27]. It may also find applications in engineering where certain concepts require visualization and interaction with 3D virtual models [28]. These potential variations of *ToothPIC* would require different graphical models corresponding to the new application however the actual program code may not need more than a slight modification.

The *ToothPIC* program is designed with the goal of making it easy to install and use, hence an installation package is developed. The package contains a tutorial that provides procedural information for using the program as well as teeth anatomy information. The program does not require any additional hardware other than standard computer and a mouse with a wheel.

All comments from both instructors and students collected during the development of the program were invaluable. It is clear that this program could not be developed without close cooperation between program developers (College of Engineering) and potential users (College of Dentistry).

5   CONCLUSION

ToothPIC is an interactive program employing 3D graphics to teach students about the tooth anatomy. Further, it uses the game-based learning paradigm to keep the students engaged in learning. The program was designed to facilitate students' self-training in tooth identification and tooth alignment skills, provide for unlimited practice time and require less student/instructor interaction while helping students more efficiently and effectively learn these basic skills. The program was developed using a variety of open-source components. The crucial part of making the program successful was the input of dentists and potential users. An evaluation of the program shows that the program achieves its design objectives, i.e., it offers an interactive ancillary tool that novice students can use outside of the classroom to provide a game-like, interactive and enjoyable self-training process for the student.

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