The Effectiveness of Computer-Aided, Self-Instructional Programs in Dental Education: A Systematic Review of the Literature


Abstract: Computer-aided learning (CAL), self-instructional programs provide an accessible, interactive, and flexible way of presenting curriculum material. In order to assess the effectiveness of CAL programs in dental education, a systematic review of the published literature comparing CAL with other teaching methods was performed. A systematic search of the published literature was performed. Articles formally assessed for inclusion had to meet the following criteria: randomized controlled trials comparing CAL with any other method of instruction, and the use of academically homogeneous dental students or dental professionals with objective, predefined outcome criteria measuring performance, time spent, and attitudes. The searches located a total of 1,042 articles; of these, only twenty-seven articles met the inclusion criteria. Further quality assessment identified twelve studies that were included in the final review. Five of the studies documented statistically significant differences in outcome measures (scores on multiple choice, written or oral tests, and clinical performance) favoring CAL over comparison group(s), while six revealed no statistically significant differences. One study documented a greater improvement in test scores in the seminar group over the CAL group. Participants' attitudes towards CAL in the included studies are also discussed. Our study concluded that CAL is as effective as other methods of teaching and can be used as an adjunct to traditional education or as a means of self-instruction.

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Key words: computer-assisted learning, computer-based instruction, dental education, self-study, systematic review

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Self-instruction has been shown to be an effective method of learning in dental education. A meta-analysis of self-instruction in dental education by Dacanay, integrating findings from thirty-four comparative studies, showed that educators who individualize their classes could expect, on average, a small to moderate positive effect on achievement. Their conclusions were in accordance with a study by Williams where it was found that self-instruction was capable of increasing cognitive knowledge significantly in a shorter period of time and with greater student satisfaction over conventional methods.

One such means of providing self-instruction is through computer-based instructional programs. Computer-based, self-instructional programs provide an accessible, interactive, and flexible way of giving multimedia presentations that utilize textual materials, visuals, sound, and motion. Since the development of the personal computer in 1981, computers have been used extensively in educational settings. Computer programs complement conventional teaching while providing a means for students to learn at their own pace. Computer-based instruction (CBI) in the health profession, also known as Computer-Aided Learning (CAL) or Computer-Aided Instruction (CAI), is becoming a popular vehicle to provide information to students, patients, and practitioners alike.

A meta-analysis of 254 controlled evaluation studies of Computer-Based Instruction (CBI) by Kulik and Kulik revealed a positive effect on students. The study revealed that CBI programs raised student examination scores by 0.3 standard deviations, produced positive changes in student attitudes toward teaching and computers, and decreased the amount of time needed for instruction. CAL in dentistry first emerged in 1971 with its introduction at the University of Kentucky.

In the past two decades, the progress of communication technology and the wide use of the Internet have made CAL programs readily available, while their availability without time constraints makes them an attractive alternative to conventional learning. There are CAL programs on the market in various dental disciplines, including: oral and gross anatomy, orthodontics, endodontics, restorative dentistry, radiology, oral pathology, geriatrics, prosth-
odontics, and periodontology. Several studies have evaluated the effectiveness of CAL versus other teaching methods in dentistry. Many of these studies, however, use the participant’s perception of his or her experience with a learning program as the only outcome measure for evaluating the effectiveness of the CAL program. In this review we sought to identify high-quality, well-designed, randomized controlled intervention studies that are available in the published literature comparing CAL to other teaching methods.

Objectives

The objectives of this systematic review of the CAL literature were to:
1. Assess the effectiveness of computer-aided, self-instructional programs in dental education, and
2. Review the published literature and develop evidence-based guidelines for the use of CAL in dental education.

Methods

Only randomized controlled trials (RCTs) comparing computer-aided learning with any other method of instruction (self-instructional or tutor-aided instruction) were considered. Only studies that included the following types of students were eligible for the review: academically homogeneous undergraduate dental students, graduate dental students, dentists, and faculty at dental schools. Studies considered for inclusion in the review had to use one or more of the following types of outcome measures: objectively measured post-test scores on multiple choice, written or oral tests; objectively measured performance on a clinical procedure or clinical interview; or objectively measured time spent on CAL programs to learn the material presented and responses to questionnaires dealing with the participant’s attitudes towards the mode of learning.

Electronic searching by an information technology expert and non-electronic searching were used. Subject-specific search strategies were developed using vocabulary mapping (mp) which included MeSH terms, text words, and index terms gathered from existing collections of articles known to be relevant. Non-electronic searching was done based on cited studies in relevant papers.

Our electronic search strategy consisted of the following:
1. MEDLINE 1966 to June week 3, 2002 using: self-study (mp), computer-assisted instruction (mp), computer aided-instruction (mp), computer-based instruction (mp), problem-based learning (mp), dental education/or education, dental (mp explode), medical education (mp) [mp=title, abstract, cas registry/ec number word, MeSH subject heading]
2. The Cochrane Library to the second quarter of 2002, including Cochrane Controlled Trials Register, Cochrane Database of Systematic Reviews, Cochrane Database of Abstracts of Reviews of Effectiveness using: self-study, computer-assisted instruction (mp), education dental (mp) [mp=title, original title, abstract, MeSH headings, heading words, keyword]
3. EMBASE (Excerpta Medica) 1980 to 2002 week 24 using terms as in MEDLINE
4. ERIC (Educational Resources Information Center) 1970 to June 2002 using: computer-assisted instruction, intelligent tutoring systems, courseware, learner-controlled instruction, and dental education
5. CINAHL (Cumulative Index to Nursing & Allied Health) 1982 to June week 4 2002 using: self-study, computer-assisted instruction, and education
6. LISA (Library and Information Science Abstracts) 1969 to May 2002 using terms as in CINAHL
7. Psycinfo (Psychological Information) 1970 to May 2002 using terms as in CINAHL
8. IPA (International Pharmaceutical Abstracts) 1970 to June 2002 using: computer-assisted instruction, self-study

One reviewer, who excluded articles clearly of no relevance to the study, initially screened the results of all searches. This screening process eliminated any studies that were not dentistry-based, lacked a comparison group, and lacked the criteria previously mentioned for types of studies, participants, and outcomes. Copies of all remaining (not excluded) articles were retrieved and reviewed by two independent assessors who judged whether they were eligible for formal assessment according to the criteria stated above. The validity and strength of the selected studies were assessed using a checklist of nine criteria that measures the strength of an intervention study adapted by Dr Jim Leake (Table 1). The studies analyzed had to meet a minimum of seven
out of the nine criteria for inclusion in this review. The two reviewers assessed the quality of the studies independently. Any differences were resolved by subsequent discussion.

Results

Description of Studies

The searches located a total of 1,042 articles, of which seventy-nine appeared potentially relevant to the review (i.e., met one or more of the criteria for considering studies in this review) and were retrieved. Many articles were immediately excluded, such as letters, review articles, editorials, and articles merely describing the development of CAL programs in dentistry without formally evaluating their effectiveness.

Twenty-seven articles meeting the criteria for consideration in this review were formally assessed for inclusion by two independent raters. The level of initial agreement on inclusion between reviewers was good, indicating that the inclusion criteria could be reliably applied (average Kappa score for agreement on decisions = 0.86). All disagreements were resolved by discussion. Fifteen of the articles were excluded, while twelve met the criteria for inclusion in this review. Included articles featured CAL programs in various dental disciplines: five in endodontics, three in orthodontics, one in oral anatomy, one in restorative dentistry, one in geriatric dentistry, and one in prosthodontics. The average score out of nine criteria for the included studies was 7.5. One study met all nine criteria, and three studies met eight out of the nine criteria (Table 2).

Methodological Quality of Included Studies

All of the included studies compared the effectiveness of a computer-aided learning group (also referred to as a simulation group) with another type of learning strategy such as tutorial teaching, seminar group teaching, lectures, or self-instruction without the use of computers. The study designs that provided the best level of evidence were those in which comparison groups were homogeneously distributed using an academic skill indicator (pre-test scores, cumulative GPA, and GPA in courses related to the CAL program) and subsequently randomly allocated to the comparison groups (Figure 1). This study design was seen in trials by Fouad et al., Mullaney et al., Mulligan and Wood, and Puskas et al. Studies not following this design that were found to provide an acceptable level of evidence (greater than seven out of the nine criteria on the quality assessment checklist) either adjusted for differences between comparison groups or performed statistical analysis to ensure homogeneity of groups. To ensure that the comparison groups did not differ in learning ability, trials by Bachman et al., Clark et al., Hobson et al., Plasschaert et al., and Sandoval et al. performed statistical analysis of pre-test scores between groups following randomization of subjects into groups while another study by Tira. reported adjusted post-test scores for pre-test scores. A randomized controlled study by Kay et al. used a Solomon three-group design, which allows for comparisons of the effects of differences in variability between groups and is able to identify any discrepancies in skill level between the groups. In another study by Luffingham, both groups were exposed to the two types of learning methods (CAL and tutorial), and test scores were then compared between the two groups to detect differences.

Quantitative Results

All quantitative results for the studies included in this review are summarized in Table 2. The effec-
Table 2. Summary of included studies and quantitative results. Included studies had to meet at least seven out of nine criteria (listed in Table 1)

<table>
<thead>
<tr>
<th>Author/Field</th>
<th>Aim of Study</th>
<th>Participants</th>
<th>Study Groups (Randomly Allocated)</th>
<th>Outcomes Measured</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bachman 1996</td>
<td>To examine the difference in effectiveness between traditional instruction and computer-based instruction in teaching the anatomy of the permanent maxillary central incisors</td>
<td>83 first-year dental students at the University of Minnesota, School of Dentistry</td>
<td>1. Group A (n=29) attended standard lecture only. 2. Group B (n=28) attended standard lecture and used computer program. 3. Group C (n=28) used computer program only. *No significant differences were found in pre-test scores among any of the three groups.</td>
<td>a. Performance on 20 multiple choice questions (MCQ) given pre- and post-intervention</td>
<td>a. No statistically significant differences among any of the three groups with respect to either pre-test or post-test scores (p-value not specified)</td>
</tr>
<tr>
<td>Clark 1997</td>
<td>To compare the effectiveness of a HyperText program versus conventional lectures to teach cephalometrics</td>
<td>52 first-year clinical undergraduate dental students</td>
<td>1. Computer group (n=26) 2. Lecture group (n=26) *No significant differences were found between the pre-test scores of the two groups.</td>
<td>a. Pre-intervention test (30 MCQ) b. Post-intervention test (150 MCQ including the 50 questions asked in the pre-test)</td>
<td>a. No significant difference between groups at start of study (p-value not specified) b. No significant difference between groups after tuition (p-value not specified)</td>
</tr>
<tr>
<td>Foadi 1997</td>
<td>To compare the effectiveness and efficiency of the computer simulation program with 1) a small-group problem-solving seminar and 2) no instruction to improve knowledge of endodontic diagnosis</td>
<td>101 third-year undergraduate dental students from 1995 to 1997 at the University of Connecticut, School of Dental Medicine</td>
<td>Assignment to each group based on pre-test scores in that the scores were sorted and students assigned to one of three groups in random order: 1. Simulation (n=34) 2. Seminar (n=32) 3. Control (n=24)</td>
<td>a. Effectiveness of program measured via a post-intervention test (20 MCQ) b. Efficiency measured by number of cases covered in unit time</td>
<td>a. The simulation group students improved significantly more from pre-to post-test than the seminar group (p=0.05) and the control group (p=0.0024). b. Students were able to cover more cases on average using the simulation program than were covered in the seminar (p=0.0001).</td>
</tr>
<tr>
<td>Hobson 1997</td>
<td>To compare the effectiveness of CAL with traditional seminars to teach orthodontic diagnosis and the basic principles of treatment planning</td>
<td>59 fourth-year undergraduate dental students</td>
<td>1. CAL group (n=25) 2. Seminar group (n=24) *No significant differences were found between the pre-test scores of the two groups.</td>
<td>a. Performance on case-based written test</td>
<td>a. The seminar group had a greater improvement in test scores than the CAL group (p=0.0001).</td>
</tr>
<tr>
<td>Ray 2001</td>
<td>To determine whether an educational intervention delivered by a computer-aided learning package improved the sensitivity and specificity of dentists' restorative treatment decisions</td>
<td>95 dentists</td>
<td>Using a Solomon three-group design: 1. Group 1 read radiographs pre-and post-CAL intervention. 2. Group 2 read the radiographs once, after the intervention. 3. Group 3 read the radiographs twice but received no intervention.</td>
<td>Dentists read 24 surfaces on each of 15 radiographs and made 360 decisions on how certain they were about restoring the tooth surface. Outcomes measured were: a. Sensitivity b. Specificity c. Area under ROC curves</td>
<td>There were no significant changes in sensitivity, specificity, or area under the curves caused by the intervention (p&gt;0.05). There was no evidence that the level of agreement between dentists improved after the intervention.</td>
</tr>
<tr>
<td>Laffingham 1984</td>
<td>To compare the effectiveness of a CAL program with traditional tutorial instruction in teaching orthodontic principles through case analysis</td>
<td>60 dental undergraduate students at the end of their first clinical year</td>
<td>1. Five groups (A) received tutorial instruction on Class III malocclusion and CAL on class II. 2. Five groups (B) received tutorial instruction on Class II malocclusion and CAL on class II.</td>
<td>a. Written test on the subjects covered</td>
<td>The CAL group scored significantly higher for both Class II instruction (p&lt;0.02) and Class III instruction (p&lt;0.01). *A comparison of the performance of groups A and B shows no significant difference between them.</td>
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<table>
<thead>
<tr>
<th>Study</th>
<th>Authors</th>
<th>Year(s)</th>
<th>Methodology</th>
<th>Participants</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mullany 1976</td>
<td>Endodontics</td>
<td>Strength of Study: 7</td>
<td>Using a slide-tape presentation in teaching clinical endodontic problems</td>
<td>54 undergraduate dental students</td>
<td>Students were divided into nearly equal groups with high and low grade point standings and randomly assigned to: 1. Slide-tape group 2. CAI group</td>
</tr>
<tr>
<td>Mulligan 1993</td>
<td>Geriatric Dentistry</td>
<td>Strength of Study: 8</td>
<td>To compare the effectiveness of a computer-based program with a literature-based educational unit in teaching clinical decision making for the geriatric patient</td>
<td>20 third-year undergraduate dental students</td>
<td>Students were matched on grade point average and randomly assigned to: 1. Computer group 2. Literature-based group *No significant differences existed on outcome measures at pre-test (p&gt;0.05).</td>
</tr>
<tr>
<td>Plasschaert 1997</td>
<td>Endodontics</td>
<td>Strength of Study: 7</td>
<td>To compare the effectiveness of a CAL multimedia program with a more traditional approach consisting of written information, without interaction</td>
<td>28 fourth-year undergraduate dental students at the University of Kentucky</td>
<td>1. Multimedia group 2. Text-based group *No significant differences were found between the pre-test score of the two groups.</td>
</tr>
<tr>
<td>Puskar 1991</td>
<td>Endodontics</td>
<td>Strength of Study: 9</td>
<td>To compare the effectiveness of CAL with self-teaching booklets in teaching diagnostic testing</td>
<td>41 undergraduate dental students</td>
<td>Students were stratified according to their pre-test scores into quartiles and randomly assigned to: 1. Computer media group (n=21) 2. Self-teaching booklet group (n=20)</td>
</tr>
<tr>
<td>Sandeno 1987</td>
<td>Endodontics</td>
<td>Strength of Study: 7</td>
<td>To compare the effectiveness of four different endodontic self-instructional review formats [slide-tape (ST), latent image (LI) simulation, computer-text (CTI) simulation, and computer-assisted video interactive (CAVI) simulation]</td>
<td>105 senior undergraduate dental students at the University of Texas, Dental School</td>
<td>1. Control (n=13) 2. Slide-tape (n=13) 3. ST-LI (n=13) 4. ST-CTI (n=13) 5. ST-CAVI (n=14) 6. LI (n=13) 7. CTI (13) 8. CAVI (n=13) *No significant differences were found between groups in endo lab GPA, jr. year endo GPA, cumulative GPA, or pre-test scores.</td>
</tr>
<tr>
<td>Tira 1977</td>
<td>Prosthodontics</td>
<td>Strength of Study: 7</td>
<td>To compare the effectiveness of a CAL course with traditional classroom lectures in teaching the Applegate-Kennedy Classification system</td>
<td>93 undergraduate dental students</td>
<td>1. CAL group—randomly selected from volunteers 2. Lecture group—randomly selected from volunteers 3. Lecture group—randomly selected from nonvolunteers</td>
</tr>
</tbody>
</table>
tiveness of computer-aided learning programs was assessed in all of the included studies by measuring the performance of participants on a post-intervention test or procedure and comparing these scores between the experimental and control groups. Five of the included studies documented statistically significant differences in the outcome measures of multiple choice test scores, written test scores, and clinical performance favoring the Computer-Aided Learning group over the comparison group with p-values ranging from 0.001 to 0.05. Six of the included studies revealed no statistically significant difference in outcome measures between the CAL group and the comparison(s) groups. One of the studies included in this review documented a greater improvement in test scores in the comparison group (seminar groups) over the CAL group (p<0.0001).

The efficiency of CAL programs in teaching a subject matter was assessed in one of the included studies by comparing the time spent by participants to learn orthodontic diagnosis and treatment planning in the CAL group versus the seminar group. It was revealed that students were able to cover more cases on average using the simulation (CAL) program than were covered in the seminar group (p<0.0001). Also, their ability to diagnose and treatment plan improved significantly from pre- to post-test.

**Qualitative Results**

The qualitative measures of each study are summarized in Table 3. Most of the studies included a questionnaire or survey to measure the participants’ attitudes towards the CAL program being evaluated and another form of learning (other than CAL). Most of the questionnaires asked specific questions that were answered on a numerical scale indicating the level of agreement with the statement. Subsequently, the mean score for each question was calculated and compared against the comparison groups. Four of the studies documented positive participants’ responses favoring the CAL program. Five studies documented no significant differences in the participants’ attitudes towards CAL versus another form of learning. Two studies did not include a questionnaire and did not document the participants’ subjective experience with respect to the educational unit in any way.

**Discussion**

The effectiveness of self-instructional CAL programs in dental education varies among the studies included in this review. For the most part, CAL is either more effective or at least equally effective as...
Table 3. Participants’ attitudes towards CAL: summary of qualitative results

<table>
<thead>
<tr>
<th>Author</th>
<th>Description of Post-Study Questionnaire</th>
<th>Main Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bachman</td>
<td>Survey asked students to rank on a scale of 1 to 5 their level of agreement (5) or disagreement (1) with a number of statements seeking to assess study participants’ feelings regarding the effectiveness, the convenience, and their overall enjoyment of the educational units.</td>
<td>Only one of the responses on the subjective portion of the post-study survey exhibited a statistically significant difference among groups (p=0.02) with the computer-lecture group enjoying the educational unit more than the other two groups.</td>
</tr>
<tr>
<td>Clark</td>
<td>Brief questionnaire (3 questions) to elicit the views of the students concerning the strengths and weaknesses of the hypertext program.</td>
<td>¾ of students enjoyed the program; less than ¾ found it easy to use.</td>
</tr>
<tr>
<td>Fouad</td>
<td>Questionnaire asked students to rank on a scale of 1 to 5 their level of agreement or disagreement with 10 statements commenting on their experiences with the simulation program and how it compared with the seminar.</td>
<td>Students thought that the program was adequate for its intended purposes and liked using it. They had varying responses on whether the CAL program was “more efficient” or “more appropriate” than the seminar.</td>
</tr>
<tr>
<td>Hobson</td>
<td>Questionnaire asked students to rank on a scale of 1 to 5 their level of agreement or disagreement with 10 statements on their perception and attitudes to the form of teaching they had experienced.</td>
<td>Both forms of teaching were rated highly to the same extent. However, more students felt that the aims of teaching had been met better by the tutorial than by the CAL teaching session (p=0.011).</td>
</tr>
<tr>
<td>Kay</td>
<td>No questionnaire was given to students.</td>
<td>N/A</td>
</tr>
<tr>
<td>Luffman</td>
<td>No questionnaire was given to students.</td>
<td>N/A</td>
</tr>
<tr>
<td>Mullaney</td>
<td>Questionnaire to elicit participants’ attitudes about the usefulness in preparing students for clinical cases, desire to take other courses by the studied methods, and preference of this method versus being instructed by an instructor.</td>
<td>Varying responses</td>
</tr>
<tr>
<td>Mulligan</td>
<td>Survey asked students to rank on a scale of 1 to 5 their level of agreement (5) or disagreement (1) with a number of statements on the subjective experience of the educational unit.</td>
<td>Four of the items were found to be rated statistically significantly higher by the computer-based subjects: degree of interest (p=.001), effectiveness (p=.001), overall enjoyment (p=.008), and desire for additional learning experiences of a similar nature (p=.001).</td>
</tr>
<tr>
<td>Plasschaert</td>
<td>Survey asked students to rank on a scale of 1 to 5 their level of agreement (5) or disagreement (1) with a number of statements on the subjective experience of the educational unit.</td>
<td>Students in the multimedia group found their learning material to be significantly less repetitive and more clearly presented than did the students in the text-based group (p&lt;.05).</td>
</tr>
<tr>
<td>Puskas</td>
<td>Survey of students’ opinions of self-instructional materials assessing the educational value, satisfaction favoring CAL, and motivation to participate.</td>
<td>No statistically significant difference was found in participants’ perception of educational value and satisfaction favoring the CAL program. The prime motivation for participation in the study was to influence changes in the curriculum.</td>
</tr>
<tr>
<td>Sandoval</td>
<td>Survey of students’ evaluation of each method of endodontic review programs.</td>
<td>Slide tape-computer text and slide tape-computer-assisted video interactive instructional methods received the most favorable overall ratings by students.</td>
</tr>
<tr>
<td>Tira</td>
<td>Survey of students’ opinions about the CAL course.</td>
<td>Students’ opinions of the CAL course were clearly favorable.</td>
</tr>
</tbody>
</table>
other methods of education while promoting positive feelings in students towards learning. The best study design for evaluating the effectiveness of CAL was randomized controlled trials where participants were randomly assigned to different homogeneous groups determined by an academic skill indicator. Subsequently, studies following this type of design or of equivalent quality were selected and included. It is, however, important to note that some of the studies that were excluded compared CAL with other methods of learning by looking at long-term retention\textsuperscript{15,20,27,40} and performance on a clinical procedure\textsuperscript{25-27} as the main outcome measure. Thus, better quality trials are needed to assess students’ long-term retention of material using CAL. Educators should seek to determine the best method of teaching that will result in greater long-term retention so that students can retain learned information and be able to apply it further into the future. Additionally, better quality trials are needed evaluating the effects of CAL programs on performing clinical procedures to establish the best method of developing clinical skills and consequently improving the quality of graduating dentists.

Students’ attitudes about methods of instruction were used in all but two of the studies as qualitative measures of the CAL program. One commonly used indicator of a program’s success is the students’ own perception of their learning.\textsuperscript{41} However, evaluating learning programs in this manner has a number of limitations if care is not taken to follow the strict guidelines mandated in qualitative research methodology.\textsuperscript{41} It is important to note that one of the pitfalls of using students’ perceptions of their learning as an evaluative measure of a CAL program is that positive attitudes may be due to the fact that the program is a new learning method that may alone create a positive response.\textsuperscript{13} This phenomenon is also known as the Hawthorne effect. In this review, qualitative results are included, but should not be regarded as the main outcome measure to evaluate the effectiveness of CAL. Instead, these qualitative data should be viewed as an indicator of students’ enjoyment and acceptance of the approach, which may then influence the students’ level of motivation towards learning using CAL.

**Conclusions: Evidence-Based Guidelines for the Use of CAL**

Our review of randomized controlled trials that examined the effectiveness of CAL in dental education indicates that the outcomes are split into two categories: studies that found no difference between CAL and other learning strategies and studies that found a significant advantage for CAL in terms of knowledge gains.

Based on these findings from thirteen studies of CAL that met our inclusion criterion, our evidence-based recommendations are:
- CAL can provide innovative and interactive ways of presenting material and therefore should be used as an adjunct to conventional teaching or as a means of self-instruction.
- CAL can elicit positive responses from students and consequently motivate students to learn.
- A CAL program that is at least as effective as other methods of learning has several potential value-added advantages (depending on how the program is designed and the students’ ease of access to the CAL modules): students can learn at their own pace, CAL lessons can be reviewed several times versus the “one time only” exposure in the lecture hall, and computer-based modules can be used literally 24/7 at convenient times when the student is free of distractions, alert, and ready to learn.

**Acknowledgments**

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**REFERENCES**