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Effect of multimedia information sequencing on educational outcome in orthodontic training

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SUMMARY The aim of this research was to compare the effectiveness of hierarchical sequencing (HS) versus elaboration sequencing (ES) models in improving educational outcome of clinical knowledge when using instructional multimedia programs in postgraduate orthodontic training. Twenty-four postgraduate and 24 undergraduate dental students participated in this study. The postgraduates were following an orthodontic speciality training programme. The undergraduates were fourth- and fifth-year dental students. Twelve instructional multimedia modules were developed, six logically sequenced (LS) discussing six different orthodontic topics. Another six modules on identical topics were sequenced according to one macro-sequencing (MS) model. The implemented MS model was either HS or ES. The only difference between LS and MS modules was the adopted sequencing model. All participants were assigned into consistent pairs of students and were randomly divided into a test and a control group. In each pair, one student studied the LS module (control group) while the other studied the MS version (test group). Pre- and post-evaluation tests of each pair of participants were performed to measure knowledge, understanding and application of each participant with regard to the discussed topic. A multilevel analysis was conducted to assess the estimated effect of the different sequencing models. The level of significance was set at 0.05.

At baseline, no significant differences ($P > 0.05$) were found in pre-test scores between groups. The HS model showed a significant effect on the scores achieved ($P = 0.05$). The test group showed a significantly higher estimated probability of correct answers to the questions ($P = 0.003$) when applying the HS model. The HS model may improve educational outcome when using instructional multimedia programs in postgraduate orthodontic training.

Introduction

Each individual's knowledge structure is unique due to his/her set of experiences and capacities. The way in which each prefers to access, interact, and interrelate with knowledge is distinct. This requires developing a computer-assisted learning (CAL) system that imparts information expeditiously as a supplement to current training programmes (Turner and Weerakone, 1992). The key to building a CAL environment is finding a balance between instruction and exploration. A framework must be created to guide and structure the learner's progress (Hoffman, 1997). This need could be readily met through the appropriate use of hypermedia if a suitable (macro-level) instructional theory was available (Hoffman, 1997; Aly *et al.*, 2005). CAL has been found to be at least as effective as other forms of instruction, but educators still do not know what makes CAL more effective or why one type of CAL is more effective than another (Rosenberg *et al.*, 2005). Hence, educational designers should concentrate on the actual design of the CAL program rather than on the delivery style used (Jaffe and Lynch, 1996; Aly *et al.*, 2004). The main design question is how the multimedia program can support learners to engage in learning activities that help them to realize the learning goals (Aly *et al.*, 2005). When designing any piece of instruction, one important question is how the instructional events should be sequenced over time. Sequencing not only relates to linear media such as textbooks or lectures (Van Patten *et al.*, 1986; Monteith, 1998) but also to non-linear multimedia programs (Aly *et al.*, 2004).

Micro- and macro-sequencing strategies

In spite of the importance of sequencing, relatively little is known about the best possible sequence (Beissner and Reigeluth, 1987). Reigeluth and Merrill (1979) identified two sequencing levels for instructional strategies: 'macro-' and 'micro-'. Instructional designers use macro-strategies to organize a set of related skills and knowledge into lessons, while micro-strategies are used to organize individual ideas, facts, concepts, principles, and procedures.

The importance of micro-sequencing in instruction was recognized and scientifically examined by Skinner (1953). Some researchers have tried to quantify the effects of micro-sequencing strategies in so-called 'scramble studies', where the effects of scrambled sequence versus logical sequence were tested (Gavurin and Donahue, 1961; Roe *et al.*, 1962). Hamilton (1964) suggested that the lack of sequencing effects in these studies might indicate that students benefit from having to make organizational efforts within a subsequence of frames (micro-sequencing) as long as the necessary overall sequence of learning material [macro-sequencing (MS)] was not disrupted. This means that macro-presentation structure might have a greater effect on learning than micro-structure. Many of the currently available prescriptions concerning sequencing are at the macro-level. Well-known MS strategies are hierarchical sequencing (HS), progressive differentiation, shortest path sequencing, and elaboration sequencing (ES; Table 1).

Hierarchical sequencing

Gagné (1968) suggested that content can be analysed into a hierarchical form by breaking intellectual skills into simpler component parts. The sequence follows a parts-to-whole organizing principle. This sequence follows the hierarchy in a bottom-up manner, where the most elementary parts at the bottom of the hierarchy are taught first while the more complex combinations of the parts are taught later (Figure 1). Validation of this sequence has shown that teaching the prerequisite knowledge first seems to facilitate the learning of the higher order skills better than teaching the prerequisite knowledge out of sequence (Gagné and Paradise, 1961; Gagné 1962).

Progressive differentiation

Ausubel (1960) proposed a sequence, which organizes content into levels of detail that approximate the way people naturally learn. General and inclusive ideas are presented first, followed by related ideas of greater specificity and detail. The effectiveness of this sequencing strategy has been tested. The results indicated that such a sequence is beneficial when unmastered prerequisite knowledge and abilities are important components of the content and when transfer is a particularly important outcome (Mayer, 1979).

Shortest path sequencing

Merrill (1978, 1980) argued that, if a subject is procedural (algorithmic) in nature, the optimal sequence of teaching can be determined by identifying the specific operations involved and the unique paths through the performance. The instructional sequence then consists of a series of sets of paths that get progressively longer. As the instruction proceeds, the procedure becomes more complex and refined.

Elaboration sequencing

As shown in Table 1, every pattern of sequencing is based on a single type of relationship within the content among the elements of knowledge domain. Reigeluth and Stein (1983) proposed an elaboration approach to MS. They

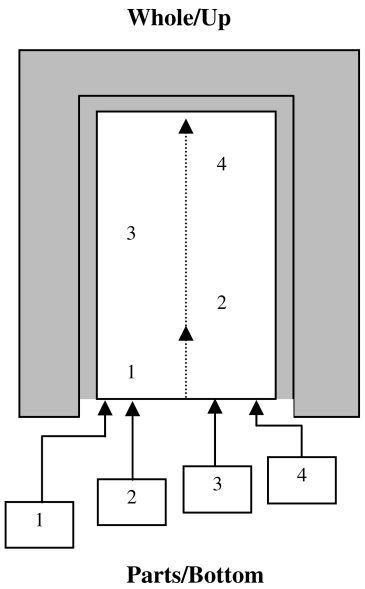

Figure 1 Conceptual map of the hierarchical sequencing model. First content (whole) is divided into more simple elementary components (parts 1–4). The most elementary parts (1 and 2) at the bottom of the hierarchy are taught first and then more complex combinations of the parts are taught later.

Table 1 Comparison between some of the widely known macro-sequencing strategies.

Macro-sequencing model	Key publication(s)	Strategy	Domain
Hierarchical	Gagné (1968)	Simple-to-complex Parts-to-whole	Intellectual skills (knowledge)
Progressive differentiation	Ausubel (1960)	General-to-detailed Top–down	Highly conceptual contents (understanding)
Shortest path	Merrill (1978) Scandura (1983)	Simple-to-complex	Procedures (application)
Elaboration	Reigeluth and Stein (1983)	Simple-to-complex Wide angle-zooming in	Concepts, principles, and procedures (knowledge, understanding, and application)

integrated much of the knowledge generated to date, such as Gagné's (1968) HS, Ausubel's (1960) progressive diffentation and Merrill's (1978) shortest path sequencing, into a comprehensive set of prescriptions referred to as 'the elaboration theory' (Reigeluth and Stein, 1983; Reigeluth, 1992). Elaboration theory developed for sequencing skill-orientated tasks has two unique features. Firstly, the most general idea epitomizes rather than summarizes the whole subject. Basically, the sequence includes the simplest ideas and is called the 'epitome lesson' (cognitive zooming). The ideas used to construct the epitome are fundamental, representative, simple, and general but not abstract. Thus, the learners are required to learn the ideas at the 'use' level rather than at the 'remember' level. Secondly, there are three different sequences, each based on one single content organization (concept, procedure, or principle). If concepts are the most important, then these are organized into taxonomies of parts. When procedural content is the most important, the simple-to-complex concept is performed by identifying the simplest possible version of the task and gradually adding more complex paths similar to the path analysis procedure (Merrill, 1978). When principles are most essential, then the simple-to-complex sequence is achieved by first identifying all the principles that should be taught and then prioritizing the principles according to their level of importance (Figure 2; Reigeluth and Merrill, 1979).

One of the major purposes behind the development of an ES model is to develop a sequencing strategy that is more holistic than the predominantly parts-to-whole hierarchical approach. This has been found to be a very effective and motivating sequence (English, 1992; Beissner and Reigeluth, 1994). In essence, elaboration theory is well founded but minimally tested (Van Patten *et al.*, 1986; Hoffman, 1997).

The aim of this study was to compare the effectiveness of hierarchical versus elaboration MS models in improving educational outcome when using instructional multimedia programs in postgraduate orthodontic training.

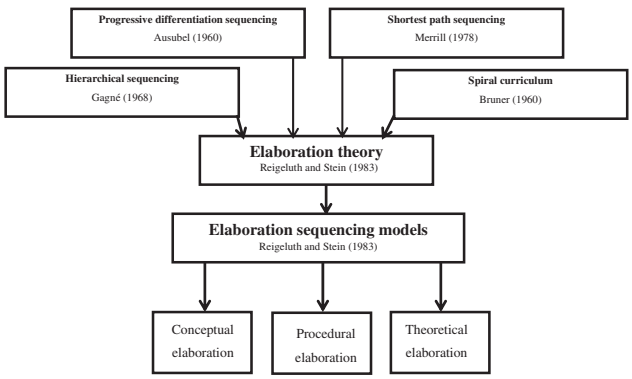

Figure 2 The contributions of the individual sequencing models from a group of closely related simple-to-complex sequencing strategies that have influenced the development of the elaboration theory.

Subjects and methods

The postgraduate and undergraduate dental students voluntarily participated in this study. All participants were contacted by electronic mail and, when possible, face-to-face communication was performed. The aim of the study was explained as well as the expected time that was to be spent when participating (7 days). Twenty-four postgraduate students following an orthodontic speciality training programme (3–4 years) at different European dental schools participated in this study. Due to the limited number of students following speciality training in orthodontics and the lack of co-operation (overloaded schedule), fourth- and fifth-year undergraduate dental students (n = 24) at the School of Dentistry, Oral Pathology and Maxillofacial Surgery, Katholieke Universiteit, Leuven, were also invited to participate.

All participants (n = 48) were assigned into consistent matched pairs of students (regardless of gender) aimed at reducing variables to a minimum. In order to control for the level of prior knowledge and language mastery, each assigned pair had to be enrolled in the same year of the dental curriculum, the same orthodontic department (postgraduates), dental school, university, city, and country.

Development of sequenced modules (learning environment) according to hierarchical and elaboration MS strategies

Six topics from the postgraduate training curriculum in orthodontics were discussed. A similar set of learning objectives was aimed at for all discussed topics. These learning goals were knowledge, understanding, and application. A commercially available software authoring system (Authorware 6; Macromedia®, San Francisco, California, USA) was used to develop six interactive multimedia courseware packages or modules. All modules were developed by the authors in collaboration with the Centre for Instructional Psychology and Technology, Katholieke Universiteit, Leuven, Belgium. Despite the fact that the production of such modules can be expensive, cost was kept to a minimum as all authors contributed to the educational design and content of the modules in addition to the overall programming.

The subject matter of these modules was logically sequenced (LS), i.e. according to how it is usually presented, discussed, and organized in regular orthodontic textbooks (Graber and Swain, 1985; Moyers, 1988; Proffit, 2000). Typically, users have complete navigational control throughout the whole of the LS modules (learner–control).

LS modules were allocated to one of the MS models (ES and HS; Figure 3) by matching the preset learning objectives of each module with the underlying logic of each MS model. Whereas MS models are designed to support the achievement of one particular set of objectives, modules are characterised by a variety of objectives. Therefore, rather than looking for a strict one-to-one relationship between modules and learning objectives, it was decided to identify the most important category of objectives and then assign the module to the model

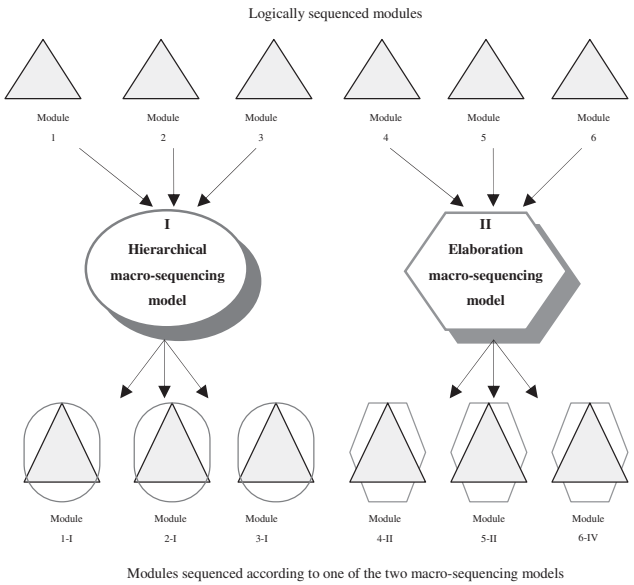

Figure 3 Each three logically sequenced modules are assigned to one of the two macro-sequencing models. This results in six versions sequenced according to the sequencing models.

that corresponded best to that most important category. Several processes were followed to achieve module allocation. Firstly, a subject matter expert was consulted to specify the learning objectives of each module. Secondly, these preset learning objectives were categorized into a knowledge, understanding, and application category, which is an aggregation of categories from Bloom's (1956) taxonomy. Thirdly, the same subject matter expert identified the most important learning objectives of each module. Finally, based on the targeted learning objectives, each module was matched to one MS model.

The validation of the HS model showed that teaching the prerequisite knowledge first facilitates the learning of the higher order skills better than teaching non-sequenced prerequisite knowledge (Gagné and Paradise, 1961). Therefore, modules, where mainly definition of technical terms and basic memorisation are of prime importance, were sequenced according to the HS model. These modules were 'finishing and retention', 'orthognathic surgery', and 'temporomandibular dysfunction'.

ES is a type of meta-sequencing model that integrates the other models (knowledge, understanding, and application). Modules, where combined knowledge, understanding, and application learning objectives are of equal importance, were sequenced according to the ES model. These modules were 'cleft lip and palate', 'orthodontic diagnosis', and 'occlusal indices'.

At this phase, 12 modules were developed, six were LS (learner–control) and six were sequenced according to one of the MS models (program–control; Figure 3). Both modules had similar interfaces and simple animation components. The subject matter of each LS module was identical to the MS version, the only difference was in the adopted sequencing model. Each MS module was viewed as an adopted LS version by controlling what the learner accessed at what point in the learning process according to the adopted MS model. This steering of the learner implies certain design features aiming to structure the module according to a certain sequence. These specific design features are:

1. Sequencing of modules is executed at the level of the main headings and subheadings (macro-level). Subject matter discussed on the screen beyond these two levels is completely under user control (micro-level).
2. Headings are always displayed on the main menu screen while subheadings are often displayed on the left side or top of a separate screen.
3. A grey colour is used to indicate that the heading or subheading texts are not yet made accessible. Once they become accessible, according to the assigned sequencing model, the grey colour will change to red indicating accessibility.

All 12 modules were displayed on the Internet. Each participant received an identification number and password. The 'Tracking File' function was implemented in all modules to assess the navigational activities (time spent, viewed, and selected sections) of the user throughout each study session.

Evaluation of two MS models and assessment of learning

Multiple choice questions. The evaluation took place by performing pre- and post-tests. The tests were displayed on the Internet using the Question Mark Perception® software (Questionmark, London, UK). Each student was assigned a password and login to access the tests. After the user logged in, a brief introduction about the nature of the multiple choice questions (MCQ) test was explained. Each test consisted of 15 MCQs and lasted for 20 minutes (a countdown timer was displayed). This pre-evaluation was carried out in order to measure the baseline knowledge of the students. After answering the pre-test, a link was sent to the user by e-mail along with an individual identification number and password for access and to allow study of the assigned module on the answered pre-test questions. All designed MCQs of the pre- and post-tests covering the six topics were validated before conducting the study. No significant differences were found between the pre- and post-test questions.

Login protocol for the developed modules. For all participants, the user password was only valid for a maximum of five logins over a period of 3 weeks. Each study session (login) was for a maximum of 2 hours.

Control and test groups. The participants were divided into two, a control and a test group, and were assigned to each other in pairs. Each pair of students studied the same orthodontic topic and each topic was studied by four pairs of students (two postgraduates and two undergraduates/topic). In each pair, one student studied the LS version (control group), while the other

studied the module sequenced according to one of the two MS models (test group; Figure 4). Post-evaluation after studying the coursework for a fixed time period was carried out (login protocol) in order to measure a student's actual and acquired knowledge, understanding, and applications. Based on the results of both tests, the educational outcome of each demonstration was estimated (Lawson, 1997).

Statistical analysis.

A multilevel analysis was used to assess the effect of the sequencing models. Firstly, a two-level model was used, with students (first level) nested in pairs (second level; Figure 5). Variables at the pair level that were included in the model were the level of education (year of the curriculum) and the orthodontic topic discussed. The variable at the student level was the assigned MS model.

Next, a three-level model was used to obtain a more detailed view of the effects of the sequencing models (deeper level). While for the preceding analysis, item scores were aggregated per student in this analysis, the item scores were analysed directly, regarding them as repeated measurements. In the three-level data structure (Figure 6), a third predictor variable was added, more specifically, the type of question variable indicating the level of processing: knowledge, understanding, and application. In addition, the estimate probability of a correct answer (pi) was transformed into logit of pi. The logit is the natural logarithm of the odds of pi.

Statistical analysis of the data was conducted using SAS for Windows (SAS Inc., Cary, North Carolina, USA). The level of significance was set at 0.05. A one-sided *P*-value was adopted to test the supposed positive effect (improved educational outcome) of the different MS models on the students' post-test and gain scores (post-minus pre-test).

Due to the limited targeted population in this study, it was difficult to determine prior knowledge differences between postgraduate and undergraduate students. However, certain measurements were considered to compensate for possible prior knowledge differences. These included assigning students into consistent pairs, considering the gain scores and using a multilevel statistical analysis.

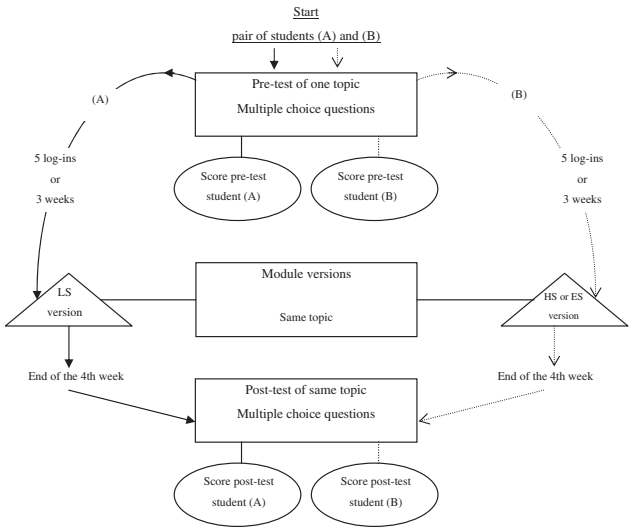

Figure 4 Conceptual map showing pairs of students evaluating one macro-sequencing model. Students A and B belong to the control and test group, respectively. LS, logically sequenced; HS, hierarchical sequenced; ES, elaboration sequenced.

Results

Two-level structure of the data

Pre-test. At baseline, there was no significant difference ($P > 0.05$) in pre-test scores between the control and test groups (Table 2).

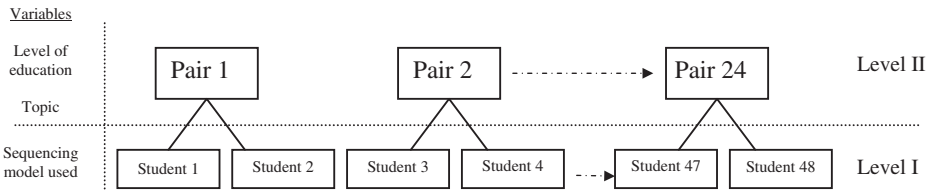

Figure 5 Multilevel structure of the data (for the aggregated item scores).

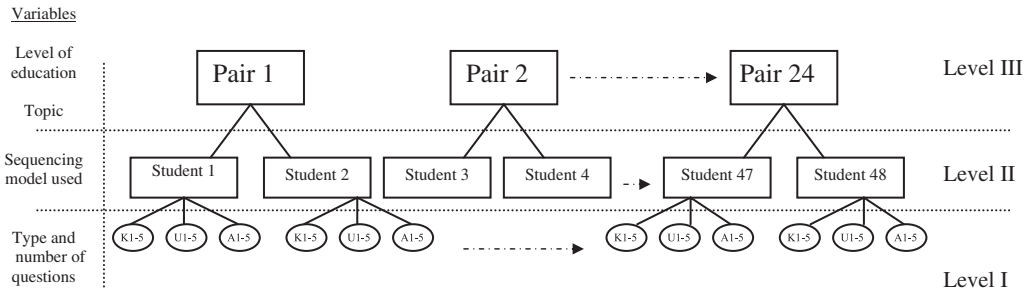

Figure 6 Multilevel structure of the data. Knowledge questions = K, understanding questions = U, and application questions = A.

General effect of MS *models after comparing pre- with post-test (gain score)*. A significant effect of the HS model on gain scores was found ($P = 0.05$). As shown in Table 2, the estimated gain score of the test group who studied the HS modules improved by 1.75 ($P = 0.05$) compared with the control group. The estimated gain score for the control group was 0.22 and for the test group 1.97. Despite the non-significant effect of the ES model, a tendency towards a small positive improvement in the estimated gain scores was observed in the test group.

Time-on-task. Participants in the test group who received the HS module spent significantly ($P = 0.016$) more time-on-task (45.16 minutes) when compared with the control group. The estimated study time for the control group was 98.53 minutes and for the test group 143.69 minutes (Table 2). The time spent on-task by the ES test group was not significantly different when compared with the control group.

Three-level structure of the data

Specific effect of MS models. The test group showed a significantly higher estimated logit of the probability of a correct answer on answering an application question when using the HS model ($P = 0.003$; Table 3). The estimated logit for the application was improved by 0.96 when using the HS model (estimated logit in the control group 0.12 and test group 1.08). This means that the probability of a correct answer was 0.53 without using a MS model but 0.75 when using a HS model. No significant effect of sequencing models was found at the knowledge and understanding levels of the subject matter.

Discussion

There is little evidence to show which macro-sequence used for designing CAL programs leads to the best learning outcomes (Hudson, 2004). Therefore, there is a need for empirical CAL comparative studies that test novel features of this type of instruction and learning environment (Aly *et al.*, 2005). This randomized controlled study aimed at evaluating the effectiveness of hierarchical versus elaboration MS models when used to sequence CAL programs in postgraduate orthodontic training.

Cognitive styles and learning enhancement

The HS model revealed significant learning gains and an improved estimate post-test and gain scores in the test group when using CAL as a learning tool. Gagné and Paradise (1961) and Gagné (1962) validated this HS model and showed that teaching the prerequisite knowledge first (parts/whole-bottom/up, depth-first; Figure 1) seems to facilitate the learning of higher order skills better than teaching the prerequisite knowledge out of sequence. However, Gagné's (1968) prescriptions about MS were mainly concerned with organizing traditional instructional media, such as lectures, seminars, and textbooks. Recently, Ford and Chen (2001) reported on the relationship between matching and

Table 3 Parameter estimates for the post-test of control versus test group at the knowledge, understanding, and application levels. ES, elaboration sequencing; HS, hierarchical sequencing; LS, logically sequenced; SE, standard error.

Parameters	Post-test		
	Estimate	SE	*P*-value
Control group			
Understanding LS	−0.57	0.24	
Understanding LS	0.03	0.24	
Application	0.12	0.19	
Knowledge	0.77	0.20	
Test groups			
HS			
Understanding	+0.06	0.33	0.43
Application	+0.96	0.34	0.003
Knowledge	+0.13	0.34	0.34
ES			
Understanding	+0.23	0.34	0.18
Application	−0.10	0.33	0.62
Knowledge	−0.07	0.36	0.58

Plus and minus values indicate improved or decreased scores.

Table 2 Parameter estimates for the pre-test, post-test, gain scores, and time-on-task of the control versus the test group. ES, elaboration sequencing; HS, hierarchical sequencing; LS, logically sequenced; SE, standard error.

Parameters	Pre-test			Post-test			Gain score			Time-on-task (minutes)		
	Estimate	SE	*P*-value	Estimate	SE	*P*-value	Estimate	SE	*P*-value	Estimate	SE	*P*-value
Control group												
LS	9.34	0.72		9.56	0.71		0.22	0.98		98.53	15.71	
LS	8.10	0.72		11.64	0.71		3.55	0.98		60.30	15.71	
Test group												
HS	−0.42	0.86	0.62	+1.33	0.77	0.045	+1.75	1.05	0.05	+45.16	20.51	0.016
ES	−0.42	0.86	0.62	+0.17	0.77	0.41	+0.16	1.05	0.43	+29.58	20.51	0.07

Plus and minus values indicate improved or decreased scores. More time-on-task indicated with plus values.

mismatching sequencing style (breadth-first and depth-first) with students' cognitive and learning style (wholist-analytic) in a CAL environment. When students learned in matched conditions (i.e. analytic individuals using depth-first instructional module), they found that they had significantly higher gain scores.

The wholist-analytic dimension monitors the routes taken by learners through a range of complex academic topics (Pask and Scott, 1973). Students with an analytic learning style perceive the world as a collection of individual parts and when receiving information they will separate it out into its parts (Cook, 2005a). This analytic cognitive style entails great similarity with the HS model adopted to sequence modules on finishing and retention in orthodontics, orthognathic surgery, and temporomandibular joint dysfunction.

Accordingly, the significant estimate of gain score improvement found in the test group might be attributed to coincident matching between the learning style of the test group (analytic students) and the implemented HS (depth-first). This speculation is supported by earlier findings linking the matching of instructional presentation strategies and students' cognitive style with improved learning performance (Pillay, 1998; Martin *et al.*, 2000; Ford and Chen, 2001; Cook, 2005b).

Of interest is the time-on-task spent by the test group who received HS modules. Examination of the tracking files showed that more time was spent on studying the modules by the test group compared with the control group (Table 2). Implementing the HS model significantly encouraged learners to invest more time on studying the modules. This may indicate that the learning style of the test group was matched. Whereas the HS model induces more time-on-task in an effective way, the more time for the ES model indicates inefficiency (Table 2).

In health professions, one study that assessed the styles defined by the wholist-analytic dimension in connection with CAL found no influence of style on achievement or attitude towards CAL tutorials (Abouserie and Moss, 1992). Recently, McNulty *et al.* (2006) concluded that a medical student's approach to learning predicts academic achievement. Thus, it is important to tailor computer applications to the individual student's intellectual and psychological profile using CAL.

However, studies in other fields found evidence to support performance improvement when student's learning style was matched. Adaptation to differences in individual learners has been proposed as a way to improve CAL. Analytic students perform better in CAL environments that encourage studying in depth-first (such as the HS model) before presenting an overview (breadth-first; Dillon and Gabbard, 1998; Chen *et al.*, 2000; Cook, 2005a). Contrary to matching learning styles, it has been suggested that the aim should be to produce balanced learners with a full range of learning capacities rather than simply matching teaching to existing learning styles (Healey *et al.*, 2005).

Aptitude–domain interaction

The HS model was hypothesised to improve the cognitive process of learning at the knowledge level (knowing that). Therefore, modules, where mainly definition of technical terms and basic memorisation are of prime importance, are sequenced according to this model (orthognathic surgery, temporomandibular dysfunction, and finishing and retention). Surprisingly, students in the test group who studied the HS modules scored significantly higher on the post-test but solely for the application questions (Table 3). In higher vocational education, students' learning styles are often application directed. This is a concept of learning in which the application of knowledge is stressed (Vermunt and Verloop, 1999). Ashley *et al.* (2006) explored undergraduate and postgraduate dental students' understanding of a good learning experience by using reflection on learning. They found dental students placed a great deal of emphasis on practical applications of their knowledge and learning through observation of the applications of their knowledge. They also concluded that individuals with this very applied learning style are attracted to dentistry as an area to study or alternatively that the demands of the course force the students into this learning style (Ashley *et al.*, 2006). The interplay between clinical experience and student performance is complex but well organized, and strategic learning styles appear to influence the benefits of increased clinical exposure (Martin *et al.*, 2000).

The above findings are likely to be applicable only to dental students, given the great emphasis placed on the learning of practical skills, and the practical application of knowledge (Ashley *et al.*, 2006). The lack of flexibility in most sequencing models, except ES, increases the challenge when solely applying one sequencing model and yet providing adequate support to the cognitive process of learning. This is especially the case when dealing with orthodontic subject matter where interaction of structured knowledge, application, and diagnostic reasoning in the clinical context are important. The ES model, by its very nature, was expected to display a significant learning improvement but this was not the case in this study. This might be due to the predominant learning characteristic of the learners in the test group, namely, a very applied learning style.

Conclusions

Based on the literature and the current empirical study, the evidence from using instructional multimedia programs in postgraduate orthodontic training indicates that:

1. The HS model may match the learning style of the majority of postgraduate and undergraduate dental students when the subject matter is orthodontic material. In such cases, an improved educational outcome may be possible at the clinical application level.

2. The HS model may influence multimedia designers and academic authorities to consider potentially deliberate goal-orientated sequencing decisions at the macro-level when using instructional multimedia programs for postgraduate orthodontic training.

Further research is needed to investigate the effectiveness of the shortest path and progressive differentiation MS models when applied to instructional multimedia programs.

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