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ORIGINAL PAPER

Developing technical expertise in secondary technical schools: The effect of 4C/ID learning environments

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Abstract In this study, the effectiveness of learning environments, developed in line with the specifications of the four components instructional design model (4C/ID model) and the additional effect of ICT for fostering the development of technical expertise in traditional Ghanaian classrooms, was assessed. The study had a one-by-one-by-two pretest–posttest quasi-experimental design. Three functionally equivalent classes of students from three similar (secondary technical) schools were randomly exposed to three different treatments. The sample consisted of 129 students. The treatment groups consisted of one control group with a regular method of teaching and two experimental groups: a 4C/ID learning environment with ICT; and a 4C/ID learning environment without ICT. The content for the treatments was selected from the secondary technical education syllabus. Technical teachers were trained to implement the interventions. After the pilot study, the materials were validated by experts and revised. Teachers were retrained. The main study, consisting of six sessions, was conducted in regular classrooms in three schools. Results indicated that a 4C/ID learning environment promotes the development of technical expertise in secondary technical education better than teaching designed in line with a regular method of teaching. Moreover, results reveal no significant difference in learning gains for the 4C/ID learning environment between the group with ICT and the group without ICT. In the final section, the theoretical, research and practical implications of the results for the instructional design and technology community as well as for educational practice, are discussed.

Keywords Building drawing · Complex cognitive skills · Integrated set of knowledge and skills · Learning tasks · Technical expertise · 4C/ID model

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Introduction

We are all aware of the fact that nowadays the knowledge and skills needed to produce artefacts (such as cars, aeroplanes, projectors, buildings) have changed radically. This is due to rapid changes in knowledge and technology. Also employers in modern organisations want to work with technicians who can solve complex technical problems. The crucial goal of technical education is to help students to acquire technical expertise (i.e. expertise to solve complex technical problems [Dale et al. 1990; De Corte 1990; Könings et al. 2005]). In Ghana, this situation is no different. A recent report by the President's Committee on Review of Education Reforms in Ghana (2002) indicates that, in Ghana, secondary technical graduates enter the professional world ill-equipped and inadequately prepared for any employment. The report indicates that only high-quality teaching and learning integrated with information and communication technology (ICT) can reduce the severity of the problem.

Experts function intelligently and smoothly in different kinds of work situations. For instance, if expert architects in a real-life situation draw a building plan (Casakin 2004; Lindekens et al. 2003), they do it by applying the appropriate opening symbols, lines and dimensions. At the same time, they consider the client's needs (aesthetic concerns, family size and financial strengths), the nature of the site and the principles of architectural drawing. Expert architects do all this simultaneously because they have acquired a coordinated and integrated set of knowledge and skills in building drawing. The acquisition of such a coordinated and integrated set of knowledge and skills requires deliberate practice or, in other words, complex learning (Ericsson 1993; van Merriënboer et al. 2002b). In this contribution, technical expertise pertains to a coordinated and integrated set of knowledge and skills for designing/drawing a single building plan by considering the local conditions as it must be acquired by secondary technical students.

Regular methods of teaching, or teaching based on classical instructional design models (e.g. Gagné 1965), have been less effective and less efficient in meeting the challenges of this highly technological knowledge society and—more specifically—for the development of technical expertise in modern education (Jonassen 1990; Merrill 2002; van Merriënboer et al. 2002a).

In the literature of instructional design and technology, the 4C/ID model (van Merriënboer 1997) is acknowledged as one of the most effective instructional design models for designing powerful learning environments that facilitate the acquisition of integrated sets of knowledge and skills (Merrill 2002, 2006; van Merriënboer and Paas 2003). The literature also contains empirical evidence about the effectiveness of learning environments designed in line with specifications of the 4C/ID model for the acquisition of technical expertise in training contexts. However, there is little or no empirical evidence about the effectiveness of 4C/ID learning environment in traditional classrooms.

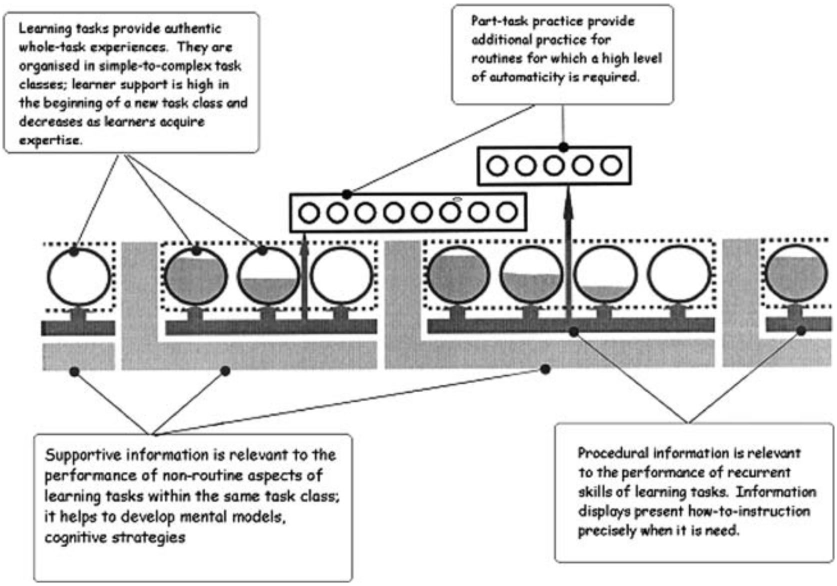
Similarly, integrating ICT into learning environments has been argued to further enhance the development of expertise (Lehtinen 2003; Pieters et al. 2003; Romiszowski 1997a, b). A study in which the 4C/ID model is validated in traditional classrooms might generate new insights into the validity of modern instructional design theories and models (4C/ID model) for different referent systems and as far as the development of technical expertise is concerned. Therefore, this study entailed the validation of the 4C/ID model with and without ICT in the context of traditional classrooms for the acquisition of technical expertise in secondary technical schools.

4C/ID powerful learning environments

The 4C/ID model elaborated by van Merriënboer (1997) proposes four components to be considered in any design task: (1) learning tasks; (2) supportive information; (3) procedural information; and (4) part-task practice. Figure 1 depicts the framework of the four components.

In the 4C/ID model (van Merriënboer 1997; van Merriënboer et al. 2002a; van Merriënboer and Paas 2003), learning tasks are authentic and meaningful real-life experiences that are provided to the learners. The learning tasks are typically performed in a real or simulated task environment, and they confront the learners with all constituent skills that make up a complex skill. The term 'complex', as used in complex cognitive skills according to van Merriënboer (1997), is used in the sense that the skills comprise a constituent set (integrated sets of knowledge and skills or recurrent and non-recurrent skills). At least some of those constituent skills involve conscious processing. The term 'cognitive', as used in complex cognitive skills, also indicates that the majority of the constituent skills are in the cognitive domain. In this regard, learning tasks allow for simultaneous practice of multiple learning goals (recurrent and non-recurrent constituent skills) so that students learn to coordinate those multiple learning goals. In other words, learning tasks allow simultaneous practice of domain-specific knowledge and cognitive strategies.

Learning tasks, Component 1, are sequenced from high to low support (Fig. 1 highlights on this). In Fig. 1, the learning tasks are represented as circles and the dotted rectangles around a set of learning tasks are referred to as 'task classes', which are used to define simple-to-complex categories of a learning task. Equivalent learning tasks belong to the same task class. Learners receive much guidance and support while working on the first learning task of a task class. That support is gradually withdrawn as indicated by the filling



Learning tasks provide authentic whole-task experiences. They are organised in simple-to-complex task classes; learner support is high in the beginning of a new task class and decreases as learners acquire expertise.

Part-task practice provide additional practice for routines for which a high level of automaticity is required.

Supportive information is relevant to the performance of non-routine aspects of learning tasks within the same task class; it helps to develop mental models, cognitive strategies

Procedural information is relevant to the performance of recurrent skills of learning tasks. Information displays present how-to-instruction precisely when it is need.

Fig. 1 Schematic representation of the four components: learning task, supportive information, procedural information, and part-task practice (van Merriënboer and Paas 2003, p. 13) of the circles. Guidance and support disappear from instruction when students are working on the last learning task. In Fig. 1, this is indicated by the empty circles of a task class and this learning task is referred to as a conventional problem (van Merriënboer 1997).

Conventional problems are recommended for assessment of whole-task performance. The learning tasks promote schema reconstruction through induction. Instructional methods that stimulate induction are mainly related to variability and mindful abstraction (e.g. analogy). To create a highly variable practice, learning tasks can be sequenced in randomised order and can differ from each other in terms of the saliency of defining characteristics, the context in which the task has to be performed, the familiarity of the task, or any other task dimension that also varies in the real world.

Supportive information, Component 2, provides the bridge between what learners already know and what they need to know to accomplish the learning tasks. Supportive information is assumed to be helpful for the learning and performance of non-recurrent aspects. It supports the development of mental models and cognitive strategies. In Fig. 1, supportive information is represented by the light grey L-shape. Supportive information promotes schema construction through elaboration. Instructional methods (e.g. guided discovery) that stimulate elaboration mainly induce activation of prior knowledge.

Procedural information, Component 3, is helpful for the learning and performance of recurrent skills of the learning tasks. Procedural information promotes schema automation through restricted encoding. In Fig. 1, procedural information is represented by dark grey rectangles with upward pointing arrows. Instructional methods that facilitate restricted encoding are for instance demonstration and examples.

Part-task practice, Component 4, consists of practice items that provide teaching of particular recurrent skills. In Fig. 1, part-task practice is represented by a small series of circles, representing practice items. Part-task practice is only relevant if the learning tasks themselves do not provide enough practice for recurrent aspects of a task to reach the desired level of automation. Part-task practice promotes rule automation for aspects of recurrent skills—that are supposed to be known accurately and fluently by heart—through compilation and strengthening. Instructional methods that facilitate compilation and strengthening are repetition, especially drill-and-practice. The next section discusses the application of the 4C/ID model in instructional settings, with reference to the context of traditional classrooms.

4C/ID model and instructional practice: Classroom teaching context

The 4C/ID model was originally designed for the learning of complex cognitive/technical skills in training settings for learning/training of application domains that require a high level of transfer. 4C/ID learning environments are aimed at complex learning by confronting learners with complex authentic learning tasks that constitute recurrent and non-recurrent skills (van Merriënboer et al. 2002a; van Merriënboer and Paas 2003). The 4C/ID model is rooted in development projects of technical training programs for complex cognitive skills in industrial and vocational settings (van Merriënboer 1997). The 4C/ID model has been validated in training contexts and found effective for conducting training that yields reflective expertise (van Merriënboer and Dijkstra 1997; van Merriënboer et al. 2002a). Reflective expertise is the ability to solve new problems, or to perform a complex cognitive skill in new situation by (1) application of domain-specific rules in performing familiar aspects of the task, and (2) the conscious use of cognitive schemata to solve unfamiliar aspects of the task. However, to a great extent, the effectiveness and usability of the 4C/ID learning environments have been tested mainly at the research level, across the domain of computer programming (e.g. van Merriënboer 1990), statistical analysis (e.g. Paas 1992, 1993), numerically-controlled computer programming (e.g. Paas and van Merriënboer 1994), and computer-based training studies (e.g. Schuurman 1999; van Merriënboer and de Croock 1992; van Merriënboer et al. 2002b). As acknowledged by van Merriënboer and Dijkstra (1997) and van Merriënboer et al. (2002a), the model has not been extensively validated on the practical level.

More recently, attempts have been made to test the efficacy of the 4C/ID model for the teaching of statistics and physics (e.g. Kester et al. 2004a, b). Notwithstanding, these studies focused on the effectiveness of the timing of information presentation for acquisition of complex skills; the studies did not actually compare the efficacy of the 4C/ID model and any other teaching strategies for the teaching of statistics and physics in school settings. Furthermore, these studies were conducted at a research level, but not in a real classroom environment/context. Applications of the 4C/ID model in more practical (industrial) settings (e.g. de Croock 1999; de Croock et al. 1998) are beginning to appear. Hoogveld et al. (2002) investigated the effect of the 4C/ID model on teachers' instructional design behaviours. This study is viewed as the first step in trying to apply the 4C/ID model directly in curriculum design in regular educational contexts.

ICT and 4C/ID learning environments for the development of technical expertise

Expert building designers do not refer to any book for dimensions of rooms and opening symbols when drawing a building plan (performing the terminal objective) (Casakin 2004; Lindekens et al. 2003). Referring to dimensions of rooms and symbols or inaccurate use of opening symbols can impede the drawing work and lead to building abnormalities (Greeno 2002). So these aspects of recurrent skills in performing the terminal objective require a high level of automaticity. Automaticity refers to the state in which a skill ceases to consume much of the cognitive capacity of the brain (Salisbury et al. 1985). This implies that automatised skills can be performed effortlessly and simultaneously with other tasks (non-recurrent skills) without interfering with those tasks. However, as acknowledged by van Merriënboer (1997), they are also inflexible and can even be dangerous when incorrectly triggered.

Recently, drill-and-practice has received renewed interest as an instructional activity that aims for the development of automaticity of subskills simultaneously with more complex thinking skills (Leshin et al. 1992; van Merriënboer 1997; van Merriënboer et al. 2004). Conscious cognitive processing is limited. Therefore, if a subskill is to be performed with speed and accuracy and without interference (as in the case of applying symbols and dimensions when drawing a building plan) with performance of the complex thinking task (e.g. reasoning about the principles of building drawing and reflecting on the client's needs, which require controlled processes), then the subskill must be learned through extensive practice until automaticity has been reached. As processing becomes more automatic, the requirements for operating space diminish, allowing for more operating space (Case 1984) for the performance of the complex thinking tasks. There is established research evidence that repetition and practice (drill-and-practice) with feedback determine the compilation and strength of a skill and hence promote the development of automatic skills (e.g. Anderson 1983, 1993; Ericsson 1993; van Merriënboer 1997). Compilation and strengthening are learning processes that enhance the development of automatic skills. Taking into consideration its processing capabilities (Kozma 1991, 1994; Seel and Winn

1997), ICT is argued as an ideal medium for drill-and-practice activities to promote compilation and strengthening to assist with the development of automatic skills. In contrast, Clark (1983, 1994, 2001) argued that media will never influence learning as they only deliver the instructional methods, which are the active ingredients for promoting learning. In other words, media might affect the efficiency of learning but not its effectiveness. Following Clark's argument, one might argue that, with effective design (such as a 4C/ID learning environment), computers cannot be used to implement drill-and-practice more effectively than flashcards, worksheets or a teacher in the development of technical expertise. However, there is evidence in the literature (e.g. Alessi and Trollip 2001; Salisbury and Klein 1988; van Merriënboer et al. 2004) to suggest that ICT can be used to implement drill-and-practice more efficiently and effectively than flashcards, worksheets, etc. This position is supported from the fact that computers provide more practice, quicker feedback and better opportunities for correcting errors than other media such as flashcard worksheets and chalkboards.

Purpose of the study

Based on the described validation studies, it is argued that, while there is robust empirical validation data to substantiate the effectiveness of 4C/ID learning environments in training contexts, there is an apparent lack of empirical validation data to support the practical effectiveness of 4C/ID learning environments in traditional classrooms, especially in secondary technical schools. The basic aim of this study was to investigate whether 4C/ID learning environments can be effective for promoting the development of technical expertise (particularly, the domain of this study) in true and vivid contexts of traditional classrooms of secondary technical schools (in Ghana) better than regular methods of teaching. Moreover, the study is intended to investigate if the use of computers for drill-and-practice to support the acquisition of part-task skills of learning tasks in a 4C/ID learning environment will yield better results than using flashcards, worksheets and chalkboards for drill-and-practice to support the acquisition of part task skills of the learning task in 4C/ID learning environments. It is hypothesised that:

- 4C/ID learning environments (with and without ICT) contribute to the development of technical expertise in secondary technical students better than a regular method of teaching.
- ICT-supported learning environments (i.e. when a computer is used as secondary medium to deliver the part-task practice of a learning task) facilitate the development of technical expertise better than powerful learning environment without ICT.

Experimental design

Considering the purpose and the context of the study as well as related practical problems, the experiment had a one-by-one-by-two pretest–posttest quasi-experimental design (Campbell and Stanley 1963; Krathwohl 1993). Three classes of students from three schools were randomly exposed to three different treatments. The treatments were (1) a regular method of teaching for the control group, (2) 4C/ID learning environments with ICT and (3) 4C/ID learning environments without ICT for the experimental groups. All treatments were designed and validated by expert instructional designers and a subject matter expert (SME) during the pilot study. Both the control group and the experimental group responded to a pretest and a posttest.

Participants

The group of participants consisted of 129 students selected from six Secondary (Technical) Schools (mean age = 18.1 years, and *SD* = 1.3 years). Secondary technical students in Ghana are introduced to a core course during the first 2 years of their program. The course includes English language, mathematics, technical skills and general science/physics. After this core course, students are required to select and specialise in one subject either from technical areas (industrial and engineering-related subjects such as technical drawing, auto-mechanics, applied electricity, building drawing or building technology and woodwork) or vocational areas (which include leatherwork, sculpture, graphic design, basketry, sewing, food and nutrition and management in living). Specifically, the participants included those who had been selected to specialise in building drawing. Furthermore, a SME and seven volunteer final-year technical teachers (who are computer literate) also participated in the study.

Design of the materials for the three treatments

The terminal objective was selected from the secondary technical building drawing syllabus in Ghana. Research materials included (1) materials and teacher guidelines for the three treatments (a 4C/ID learning environment with ICT, a 4C/ID learning environment without ICT, and a regular method of teaching) and (2) assessment tasks identical for all three treatments. All three treatments were designed to support the learners to achieve the same terminal objective of ‘designing a single building plan based on the local conditions’. The regular method of teaching (for the control group) was specially designed based on classical principles of instructional design (e.g. Gagné 1985; Gagné and Briggs 1979; Jonassen et al. 1989; Leshin et al. 1992). This means that a regular structure was followed: activating prior knowledge, presenting relevant information, exercises made by the students and continuous feedback by the teacher. The 4C/ID learning environment treatments (for the two experimental groups) were designed based on the framework of the 4C/ID model. The content for the three treatments was also identical and based on 13 topics selected from the syllabus. The information on the topics was selected from the required textbook (Greeno 2002) and some were provided by the SME. Each treatment consisted of four lessons, and the instructional time for each lesson was 90 min (this is the normal time for two teaching periods in secondary technical schools in Ghana). The treatments varied with regard to the following elements of the instructional approach: (1) instructional tasks; (2) instructional strategies (teaching methods); (3) support from the teacher; and (4) the use of instructional media.

The instructional tasks for each lesson of the regular method of teaching consisted of either three or four specific instructional objectives and content/topics (information) related to each specific objective. Each specific instructional objective (e.g. the student can identify the standard facilities required in a single building structure; the student can describe the basic environmental conditions in designing the structural members) was covered with information on a simple task required to help learners to acquire a specific learning capability (e.g. ability to identify elements of a building structure; ability to identify the type of foundation). In order for students to achieve the instructional goal for each lesson, they have to achieve separately the learning capability (an isolated knowledge or skill) under each specific instructional objective in a lesson. However, the instructional tasks for each lesson (task class) for the 4C/ID learning environments (with and without ICT) consisted of three equivalent (complex) learning tasks, supportive information (e.g. description of how to choose and sketch/draw a solution, by reflecting on the client's needs, to produce a design chosen), procedural information (e.g. definition and explanations with examples of 'opening symbols') and part-task practice (e.g. drill-and-practice on opening symbols and dimension signs). The learning tasks in each lesson were similar/equivalent in terms of their difficulty and in the sense that they share the same body of underlying knowledge; but they differ in terms of their context and familiarity of performance in real-life situations. Each learning task of a task class confronted the learners with a coordinated and integrated set of knowledge and skills (recurrent and non-recurrent constituent skills) that constituted the performance of the task class or the whole task.

In the regular method of teaching, the main instructional strategies (teaching methods) were activation, lecture (presentation and explanation), question/discussion, demonstration/examples and drill-and-practice. The learners received full support from the teacher throughout the lesson. However, in 4C/ID learning environments, a different set of instructional strategies/methods (e.g. inductive expository, guided discovery, modelling examples, case study, cognitive feedback) was used. As with the regular method of teaching, activation, demonstration and drill-and-practice were also used. Support from the teacher withdrew as learners were working towards the last learning task of a task class.

As it has been argued in the previous chapter, drill-and-practice can easily and effectively be delivered by flashcard and worksheets. Specifically, in the 4C/ID learning environment without ICT chalkboard, worksheets and flashcard were used in drill-and-practice exercises (write the correct answer, matching and recognition) to promote repeated practice of the recurrent constituent skills of the learning task that required a high level of automaticity. However, in the 4C/ID learning with ICT, instead of using chalkboard, worksheet and flashcard; ICT was used in drill-and-practice exercises (write the correct answer, matching and recognition). The use of ICT to deliver the part-task practice is necessitated by the proposition that ICT would probably deliver drill-and-practice in a 4C/ID learning environment better than any other medium. The Questionmark Perception Software was used to present the drill-and-practice tasks on the computer screen.

Variations in the regular method of teaching and 4C/ID learning environment treatments were based on three aspects of the instructional approach: the instructional tasks, the instructional methods/strategies and the support from the teacher. The variation in the 4C/ID learning environment without ICT and 4C/ID learning environment with ICT treatments was based on instructional media. These variations were based on the assumed effectiveness of 4C/ID learning environments and ICT for the acquisition of technical expertise in the traditional classrooms under study.

Assessment tasks

The assessment tasks consisted of pretests and posttests assessing retention and transfer (Mayer 2002) and containing both multiple-choice questions and essay-type questions. The tests consisted of 26 pretest assessment items (13 retention and 13 transfer test items) and 26 posttest assessment items (13 retention and 13 transfer test items). Four questions (two retention and two transfer) were constructed based on each of the 13 topics selected from the syllabus towards the achievement of the terminal objective.

The retention test items (e.g. The height of a single building structure is calculated from what level?) were designed to assess if the learners had mastered the recurrent constituent skills of the complex technical skills (technical expertise). The retention test items were closely related to the procedural information and part-task practice items. The transfer test items (e.g. Land has been earmarked for a construction of a community centre, but the land has been found to be a made up ground, what will happen to the structure if the right method in designing is not applied?) assessed if the learners had mastered the non-recurrent constituent skills of the complex technical skills (technical expertise). They were very dissimilar to the part-task practice items. Reliability coefficients for pretest and posttest (retention and transfer) for the present study were 0.67 and 0.68, respectively.

Procedure

Technical teachers were trained to master how to deliver the treatments as intended to ensure treatment fidelity in the ecological (classroom) setting (Krathwohl 1993). They were instructed to teach according to how they were trained. After a pilot study had been conducted, the teachers were retrained. The treatments for the main study were randomly assigned to three schools. The schools did not know to which treatment they belonged. Each treatment consisted of six sessions that each took 90 min. The lessons took place in the regular classroom of each group. During the first session, the pretest was administered by the researcher in about 40 min.

The trained teachers conducted the teaching for the subsequent four lessons. The main researcher monitored the implementation of the treatments. The teacher (for the control treatment) presented the regular method of teaching systematically as designed, and in accordance with the order of sequence of the specific instructional objectives in the lessons. The learners received full support from the teacher throughout the lesson. The teacher talked for approximately 70 min. He used to answer most of the students' questions during question time. Similar strategies were used to teach lesson 2, 3 and 4 under the control treatment.

Teachers (for the experimental treatments) also presented the experimental treatments systematically as designed. Unlike the regular method of teaching, the teacher used about 40 min to support the learners and the learners used approximately 50 min to work on the learning tasks. Similar strategies were used for all the lessons in the experimental treatments. However, learners received additional information on part-task practice during the performance of learning tasks 1 and 2 of the second lesson (session 3) and learning task 1 of the fourth lesson (session 5) of the experimental treatments. In the 4C/ID learning environment without ICT group, flashcard, worksheet and chalkboard were used in drill-and-practice to present the part-task-practice of the learning tasks. In the 4C/ID learning environment with ICT group, ICT was used for drill-and-practice to present the part-task practice of the learning tasks.

The researcher administered the posttest assessment during the sixth session of each treatment. The administration took approximately 45 min because of the additional 2 perception test items. The pre- and post-assessments were submitted to a naive SME (who did not know which school belonged to which treatment) for blind marking. The main SME re-marked the tests and differences were discussed with the researcher.

Results

The dependent variable was the learning gain (posttest scores minus pretest score); this was to accommodate the differences, even not significant, between the groups. The independent variable was the three treatment conditions. Analysis of variance (ANOVA) was used.

It was not practical and feasible to randomly assign individual students to the treatment groups. However, the assumption was that, because the students were selected from three similar class groups (pursuing the same course on building drawing) from three schools, they would be functionally equivalent with respect to the achievement of the terminal objective. An ANOVA involving pretest scores revealed no differences between the three groups of students. Table 1 provides an overview of the mean scores.

Students' performance on the pretest and posttest

An ANOVA revealed a statistically significant difference between students' performances on the pretest and the posttest ($F[1, 126] = 768.97$, $p = 0.000$, $\text{eta}^2 = 0.86$). The performance of the three groups on the posttest was better than the performance of the three groups on the pretest. Table 2 depicts the mean scores for the pretest and the posttest.

Learning gains among the three groups

Analysis of variance (ANOVA) for the learning gains revealed a main effect for the treatment ($F[2, 120] = 18.58$, $p = 0.000$, $\text{eta}^2 = 0.24$). The LSD multiple comparison test revealed that:

1. Students in the 4C/ID learning environment with ICT group experienced greater learning gains ($M = 10.06$) than students in the control group ($M = 5.44$).
2. Students in the 4C/ID learning environment without ICT group experienced greater learning gains ($M = 8.84$) than students in the control group ($M = 5.44$) (see Table 3).
3. There was no significant difference between the two experimental conditions in terms of their learning gains.

The 4C/ID learning environment with ICT group and the 4C/ID learning environment without ICT performed equally well.

Table 1 Overview of mean scores of the pretest

Condition	*N*	Mean	*SD*
1. Regular method of teaching	42	6.68	3.16
2. 4C/ID learning environment without ICT	45	5.61	3.38
3. 4C/ID learning environment with ICT	51	6.15	2.98
Total	138	6.13	3.18

Table 2 Overview of mean scores for pretest and the posttest

Testing	Condition	*N*	Mean	*SD*
Pretest	Regular method of teaching	41	6.82	3.07
	4C/ID learning environment without ICT	41	5.72	3.29
	4C/ID learning environment with ICT	47	6.30	2.96
	Total	129	6.28	3.11
Posttest	Regular method of teaching	41	12.26	2.53
	4C/ID learning environment without ICT	41	14.46	2.64
	4C/ID learning environment with ICT	47	16.36	3.34
	Total	129	14.48	3.33

Table 3 Overview of mean scores of learning gains among three groups

Condition of treatment	*N*	Mean	*SD*
Regular method of teaching	41	5.44	3.46
4C/ID leaning environment without ICT	41	8.84	3.12
4C/ID learning environment with ICT	47	10.06	3.36
Total	129	8.20	3.83

Discussion

This study aimed at exploring the effectiveness of two versions of a 4C/ID learning environment (with ICT and without ICT) in terms of the acquisition of a coordinated and integrated set of knowledge and skills related to building drawing in secondary technical schools. To achieve the goal of the study, the following research hypotheses were formulated:

- Innovative teaching methods (4C/ID learning environments with and without ICT) contribute to the development of technical expertise among secondary technical students better than regular methods of teaching.
- ICT-supported learning environments facilitate the development of technical expertise better than powerful learning environments without ICT.

The results of the experiment support the hypothesis that a 4C/ID learning environment contributes to the development of technical expertise (expertise in building drawing) in secondary technical students better than a regular method of teaching. This result indicates that, relative to the control group, the experimental group was better able to solve design problems that required reasoning, reflection and recall of procedures, facts and concepts. This result is consistent with the findings (e.g. De Corte 2003; Merrill 2002; van Merriënboer et al. 2002a; van Merriënboer and Paas 2003) that a 4C/ID learning environment facilitates complex learning or, in other words, promotes the acquisition of coordinated and integrated sets of knowledge and skills. As the result adds new insight to the effectiveness of the 4C/ID model, it increases the generalisability of the 4C/ID model. In simple terms, the result implies that the 4C/ID model is robust for different referent systems. In addition, indirectly, the result provides empirical validation for the theoretical knowledge base of the 4C/ID model. Moreover, the result contributes to understanding of the effectiveness of the 4C/ID model with regard to the acquisition of integrated sets of knowledge and skills. More specifically, in this study, what promoted better performance of the experimental groups can be explained by referring to some essential ingredients in 4C/ID learning environments that were absent in the regular method of teaching. The active ingredients included the learning tasks, the instructional strategies (such as guided discovery, modelling examples, case studies, cognitive feedback) and the gradual withdrawal of support.

Even though 4C/ID learning environments yielded more effective learning of building design compared to a regular method of teaching in the traditional classroom context, there were some implementation and methodological factors that might have constrained schema construction. With respect to the methodological factors, first, the duration of the intervention or the experiment could not be extended beyond six lessons. This is because the academic calendar (formally designed by Ghana Education Service—Ministry of Education) of the target group (selected schools) should not be disturbed too much. Second, from the point of view that the intervention (4C/ID learning environment) should be implemented within the vivid and strict context of traditional classroom teaching of secondary technical schools, the time allotted to each lesson also could not be extended beyond 90 min. This made the entire duration for the implementation of the intervention limited and perhaps inadequate for demonstrating the full impact of the intervention (van Merriënboer et al. 2002a).

With respect to the implementation factors, to a very large degree, the teachers who were trained to teach the interventions taught them as designed. However, because the interventions were new to them and despite the intensive training of the teachers, it was observed during the implementation of the experimental teaching that teachers sometimes overlooked certain techniques. Moreover, it seemed that the learners were novices to the 4C/ID learning environment teaching; they pointed out that the (last) learning tasks in the lessons were highly demanding and needed (too much) cognitive capacity. However, explanation and support from teachers were not always regarded to be sufficient. Learners always asked for extension of time at the end of each last learning task of a task class.

These factors, as observed during the performance of the last learning task of each task class, made the learners so overwhelmed, uncomfortable and discouraged that they might have had a negative impact on the cognitive processing capacity of the learners. Having a negative impact on the cognitive processing capacity of the learners could have suppressed the full and effective construction of schemata (Foshay et al. 2003; Merrill 2006; Sweller et al. 1998). This implies that a full and more effective construction of schemata could have been achieved if the teachers had provided more support to the learners in the form of hints, had asked the students to read, or think or reason around the supportive information (previously given), or had consulted a chart during the last learning tasks in the lessons. Therefore it is proposed that 4C/ID model might even foster better learning of complex technical skills in the traditional classrooms if teachers give learners cognitive support in the form of hints, ask the students to read or reason around the supportive information (previously given), or consult a chart when working on the last (assessment) learning task. This proposition is suggested not to change the 4C/ID model but to adapt the 4C/ID model to suit particular elements of the referent system. The proposition needs to be further investigated and validated.

The (regular) teaching methods used in secondary technical schools in Ghana often do not lead to effective teaching (Anamoah-Mensah 1998). In this study, the regular method of teaching differs from the teaching methods used in secondary technical schools in Ghana. This is because the regular method of teaching was especially designed based on classical instructional design principles. Although the regular method of teaching was not as effective as the 4C/ID learning environments in terms of the acquisition of technical expertise, it resulted in learning gains. This implies that (in Ghana), if the teaching methods used in secondary technical schools are designed in line with instructional design principles, better learning would be likely. This proposition should be further examined.

Despite the fact that the mean score of the 4C/ID learning environment with computer group ($M = 10.06$) is higher than the mean of the 4C/ID learning environment without computer group ($M = 8.84$), ANOVA revealed no statistically significant difference between the two groups of learning gains. The use of low-cost media (e.g. worksheets, flashcards) and ICT resulted in similar learning results. Thus, low cost media for drill-and-practice (in terms of a 4C/ID learning environment for strengthening cognitive rules in the working memory) are as effective as ICT. This insight complements theoretical understanding (e.g. Clark and Salomon 1986; Russell 1999) that any effective teaching method can be delivered to students by a variety of media (Clark 2001) with similar learning gains.

The finding of no significant difference in the learning gains of the 4C/ID learning environment with ICT and the 4C/ID learning environment without ICT, together with other findings (e.g. Clark 1983, 2001; Russell 1999), communicates to instructional technology researchers that they should search for other means of using ICT that could produce differences in learning. Again it is shown that achieving high-quality teaching aimed towards the achievement of modern aims of education depends more on the systematic design of the learning environment than on the use of ICT. The findings provide substantive evidence that, with the systematic design of powerful learning environments, low-cost media can be equally effective as ICT for the acquisition of expertise in traditional classrooms of secondary technical schools. This implies that the kinds of tasks that we give to learners are more important than the means that we use to deliver them. This is an important positive finding for developing countries (specifically in Ghana) which have limited financial resources but have the conception that ICT is the only means to achieve quality in teaching. However, this result should be generalised with caution as the present study specifically focused on computer drill-and-practice for the acquisition of part-task skills. To generalise the results to the acquisition of complex skills of technical expertise, further study should be conducted in similar contexts by using ICT to implement other components of the 4C/ID model, such as the learning tasks or the supportive information.

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