# Iterative design and evaluation of an e-learning tutorial: a research-based approach

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## ABSTRACT

This paper introduces the computer-aided instruction (CAI) tutorial *Karnaugh*, outlining its design, development and evaluation. *Karnaugh* is used for supplementary learning in the module *Computer Systems: Fundamental Concepts*.

E-learning applications require rigorous evaluation of their functionality, learning content and usability. In the case of *Karnaugh*, this was done in a participative action research approach over two years. Evaluation and reflection occurred in iterative cycles, followed by active responses in the form of revised designs, with the researcher-designer playing a participative role as *Karnaugh* evolved through five variants. Complementary usability evaluation methods were used, namely heuristic evaluation, end-user questionnaires and interviews. The evaluation criteria were based on an adaptation of Squires & Preeces' 'learning with software' heuristics.

The unexpected discovery of some flawed data provided lessons in questionnaire administration.

### CATEGORIES AND SUBJECT DESCRIPTORS

H.5.1 [**Information Interfaces and Presentation**]: Multimedia Information Systems – *evaluation/methodology;*

K.3.1 [**Computers and Education**]: Computer Uses in Education – *computer-assisted instruction (CAI).*

### KEYWORDS

Design, Human Factors, Measurement.
CAI tutorial, e-learning, evaluation criteria, evaluation methods, learner-centred design, participative action research, usability.

## 1. INTRODUCTION

The Centre for Software Engineering (CENSE) in Unisa's School of Computing is re-engineering its interactive computer-aided instruction (CAI) applications that were originally developed in the 1990s. E-learning applications – particularly those in the form of CAI tutorials – are very different from commercial task-based software. Learners, often novices, must be able to use a system before they can even begin to engage with the functions and learning content. Usability of e-learning applications is thus currently an evolving focus area. We have been using a participative action research approach which embodies iterative cycles of active design, evaluation and reflection. From the various usability evaluation methods (UEMs), we selected empirical methods such as heuristic evaluation and surveys via questionnaires and interviews [8, [15]. Evaluation of e-learning should address functionality, usability, interaction design, and learning effectiveness. Ardito et al. [3] state that pedagogic usability, learning tools, content, interfaces, and tasks aimed at the learning outcomes, should all be considered, as well as conformance of the design to traditional usability guidelines. There are specialized requirements for evaluating educational software and web-based learning [16, 17]. Usability evaluation of e-learning is different from that of conventional software, in that functionality and usability are tightly linked [11].

This paper sets out to answer two research questions with the CAI tutorial *Karnaugh* as target system:

1. How can the design, redesign and evaluation of e-learning be supported by an action research ethos?
2. What kind of findings emanate from the various evaluation methods?

Section 2 sets out the context and content of *Karnaugh*, while Section 3 outlines the research design. Section 4 introduces the design of *Karnaugh* and Section 5 presents the findings of the evaluations.

## 2. BACKGROUND

Some definitions of e-learning associate it only with the use of the Internet and Web. We subscribe to a broader approach that views it as teaching and learning via multiple information technologies, including CD-based software, such as CAI tutorials and multimedia lessons.

### 2.1 Context of '*Karnaugh*'

UNISA is an open distance-learning (ODL) institution. Most students live in South Africa, but there is an emphasis on outreach to the broader Africa. The learner profile is changing

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from part-time students to young, full-time learners, mainly from historically disadvantaged groups, some of whom study at UNISA's regional learning centres. Communication is by conventional mail, but tutorial matter is also available online. Computing students, by definition, have access to PCs, but not always to the Internet.

The 1st level module, *Computer Systems: Fundamental Concepts*, (COS113W) addresses the basics of hardware and software, and has some 1000 registered students annually. Two thirds of these students take it to completion and write the examination. The tutorial matter comprises a text book, a study guide and regular tutorial letters that include solutions to assignments. The module teaches the use of *Karnaugh* diagrams which is a convenient way of representing Boolean functions. The diagrams can be used to simplify Boolean functions by application of a set of rules. They are applied in two assignments and, together with background material, relate to about 25% of the examination paper.

### 2.2 Content of the CAI Tutorial '*Karnaugh*'

The interactive multimedia CAI lesson, *Karnaugh*, was custom-built as optional supplementary study material for COS113W. It has tutorial functionality [2] and offers extensive practice opportunities as it alternates teaching segments with exercises. Instructional transactions involve two-way transfer of knowledge and skills. *Karnaugh* was designed, evaluated and released as a tutorial on a diskette in 1992 and saw effective use for 13 years, with one revision in 1998. When it was scheduled for re-engineering in 2005, the present module leader led the project. The general approach and subject matter were re-used, but with major extensions. The lesson was made more effective because human-computer interaction (HCI) aspects such as fonts, backgrounds, screen displays, colours, colour-coding, and design of the interaction, were improved. The 2005 version was developed on the multimedia authoring platform, *Quest* 7.0 as optional study material, and is sold at a reasonable price. It is also available for use, free of charge, in UNISA's computer laboratories, where many students can access it.

The current version of *Karnaugh* is structured into sub-lessons: *Introduction, Background knowledge, Sum-of-minterms, Karnaugh diagrams and Simplification of Boolean expressions*, each with its own subsections. Learners choose which to do, in what sequence, and how many times. Theoretical concepts, processes and examples are presented step-wise, illustrated by graphics, pictures and developing animations. Tutorial units are interspersed with exercise-and-practice and each sub-lesson ends with a summary for revision. Karnaugh diagrams come from a well-structured computational domain where the exercises demand cognitive skills and each exercise has a single correct solution. This is in contrast to ill-structured domains where a variety of acceptable solutions exist [9, 10]. Most questions have a fill-in-the-blank/s format. Feedback and explanations are provided, with options to go back to examples or theory sections. Second attempts must be made after wrong answers.

*Karnaugh* caters for different stages of learning, offering students the option to omit theory and worked examples and a choice between basic or more complex questions. *Karnaugh*'s purpose is non-threatening learning support. It does no formal assessment or learning management and, although there is an optional capstone test, the score is not recorded.

## 3. RESEARCH DESIGN: PARTICIPATORY ACTION RESEARCH

An action research (AR) approach [12, 13] was used to design, develop and evaluate *Karnaugh*. AR can incorporate various research methodologies. It generates action outcomes relevant to the immediate context and research outcomes that inform future work. It is well suited to educational research, where developing artefacts or interventions are studied over a series of cycles. Based on a participative, practitioner-researcher approach, it functions as a change agent as it addresses real-world problems that require action. AR processes [4, 5, 7, 18] are:

- *Cyclic*: Iterative steps – see Figure 1 – occur longitudinally over time.
- *Participative*: Researchers and users collaborate, often with the practitioner-researcher investigating and planning evaluation of his / her own work, hence the central role in the cycles of Figure 1.
- *Qualitative*: Data is often more verbal than numeric, although quantitative methods are also used.
- *Reflective*: Critical reflection on the process and outcomes occurs within each cycle. It is used to plan and design the next actions.
- *Responsive*: AR responds and adapts to findings of previous cycles. Finally the cycle of Figure 1 closes in on a close-to-optimal solution.

The iterative research, responsive development and formative evaluation done on *Karnaugh* since its inception in 1992 is in line with the generic AR model in Figure 1. The researcher-designer (who is the present module leader) has a central involvement in the series of cycles; each cycle involving action, observation and evaluation. Reflection and responsive actions in the form of improvements lead to the next cycle, where participative inputs by peers and learners are again used to refine the artefact.

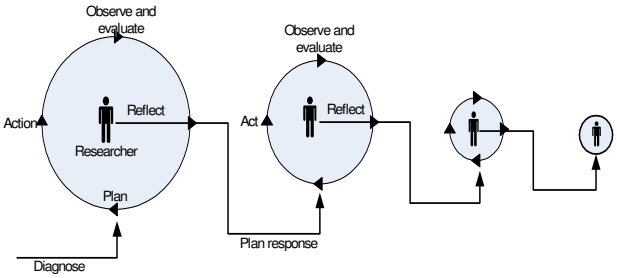


**Figure 1. Action research model (diagram synthesized by De Villiers, 2005)**

Design and evaluation are not separate, discrete stages in AR. They occur alternately in a tightly-linked, integrated way, continuously informing each other within the cycles. To simplify presentation, however, they are described under separate headers in this paper. The following two sections focus, respectively, on the process and features of design and on the evaluation events and findings.

## 4. DESIGN OF *KARNAUGH*

In a participative design approach, the 2005 team comprised the researcher-designer, UNISA peers, programmers, and a graphical designer working in a strong collaborative partnership. The design, developed on the multimedia authoring platform *Quest* 7.0, has several new and distinct features.

Earlier versions had simple navigational options, while *Karnaugh* now has increased supportive learner control; its hierarchical navigation allows selection of branches. To orient users, up-front information explains the navigation options and the lesson structure. Novice users are shown a display giving a bird's view of the contents.

The original *Background knowledge* section consisted only of a test. Now it has informative subsections on binary numbers, logical expressions, truth tables, logic circuits and Boolean expressions. Worked examples and exercises with meaningful feedback are included. The *Sum-of-minterms* section was completely redesigned and greatly extended. Most examples and exercises in the *Karnaugh diagrams* and *Simplification of Boolean expressions* sections were not changed, but more were added, as well as supplementary tutorial matter. Each section ends with a graphical summary. The test at the end, in the form of a game, was taken from the first version.

In particular, the look-and-feel changed completely as HCI aspects were improved in line with current practices. The evaluation of another CAI re-development [6] had identified some inadequacies. In an extended action research approach, cognizance was taken of these issues and new features were included, offering different functionality to new and previous users. Furthermore, hot-word hyperlinks to definitions were inserted in tutorial segments, examples and exercises. Students had wanted to choose the degree of difficulty of exercises, so a multi-option button was developed (lower left corner of Figure 4), which allows users to choose theoretical information (I), worked examples (E) or, in the context of exercises, do basic (QB) or complex questions (QC). This permits different ways of use at different stages of learning. By default, a learner can do all the options by merely using the <Forward> button and this is the approach expected from novice users. In some cases, the feedback after errors includes a <Help> link.

Due to its rigid computational domain, the learning theory foundation of *Karnaugh* is mainly objectivist, using a behaviourist stimulus-response-reinforcement approach. It also combines paradigms as it sets out to support true insight and cognition, and to anchor learning in authentic contexts. Concepts are taught by multiple perspectives on a theme, using text, figures, graphics, evolving animations, and examples. This approach supports learning gain. Figure 2 shows how a question that was answered incorrectly by a learner, receives feedback explaining why it is wrong. Figure 3 displays colour-coded feedback following a wrong answer. The boxed 'QB' and 'A' are icons indicating a basic question and a response to the answer respectively.

In a novel analogy, a soccer player character provides information and informality after complex sections. Following complex sections, screen displays present soccer activities – e.g. a soccer player bouncing a ball on his head or scoring a goal while giving commentary – to help users take a break. Figure 4 shows clips of such screens, depicting the theme character. It also shows the distinct multi-option button in the lower left-hand corner where the learner can choose tuition information, examples, or exercises with the option of basic or complicated questions. After completing any of the options, the user can use the button and make another choice. A Karnaugh diagram is a 2-D representation of a 3-D spherical phenomenon, for example, the left side of a Karnaugh diagram should, in fact, be joined continuously to the right. Hence the significance of the ball, since a soccer ball is a spherical analogy subdivided into blocks. The soccer player character contributes by providing information and participating in meaningful learning activities.

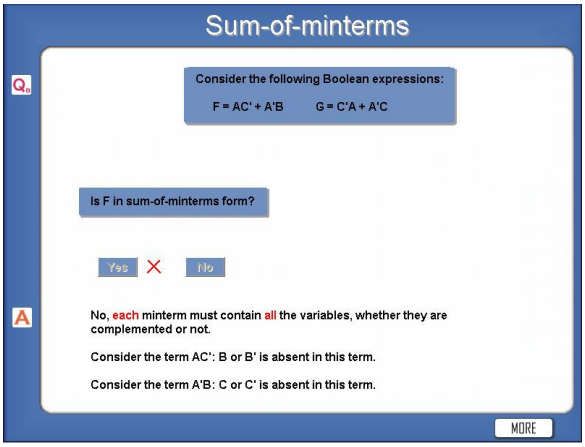


**Figure 2: Question, response, and feedback**

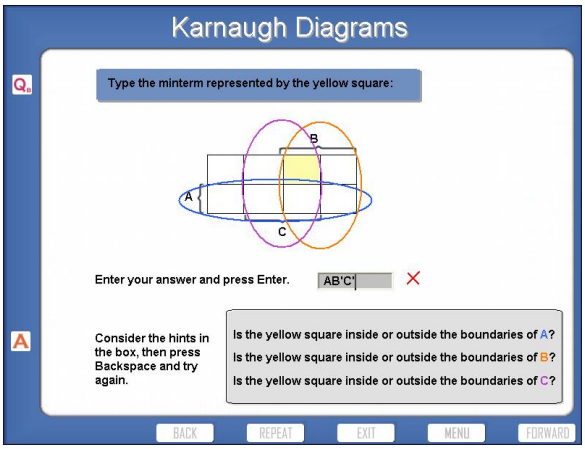


**Figure 3: Question, animation, response and feedback**

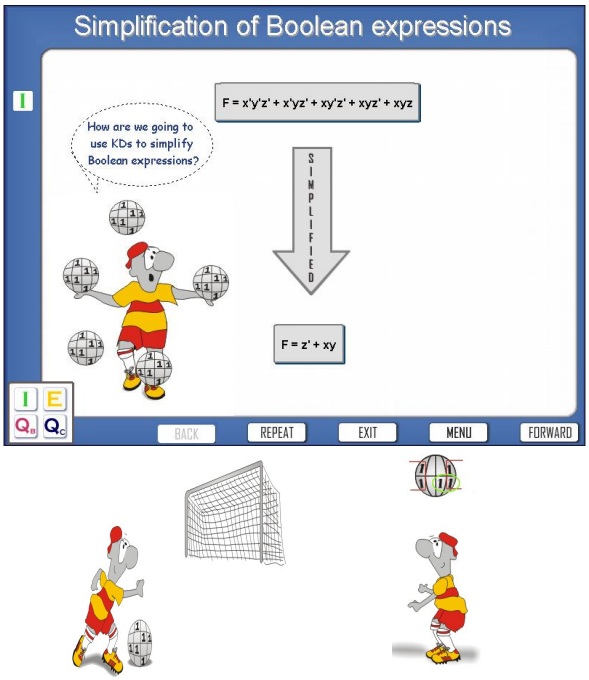


**Figure 4: Top to bottom: the logo theme character; two soccer player recreational clips**

# 5. EVALUATION FINDINGS

Formative and summative evaluations have been conducted throughout *Karnaugh*'s lifecycle. Comprehensive evaluation was done on the original version (V1), as its processes and exercises were tested during development. This paper concentrates on further evaluations, formative and summative, on the 2005 redevelopment to examine, improve and expand the product. The UEMs used in two action research cycles (Fig. 1) to plan responses and commence new cycles, were heuristic evaluation (HE) by the designer's peers; questionnaire survey evaluation by end users (students); and interviews with students. *Karnaugh* V2.1 underwent HE by expert peers prior to release, leading to V2.2, which was evaluated in a learner survey, resulting in V2.3. After a year of use, the same evaluation processes were repeated, leading to V3.1 and V3.2 respectively. Finally, an interview survey was done with a few students. By this time the cycles had closed in and the system was virtually problem-free. Rather than repetitive reporting in a sequential format, the findings of the two HEs are integrated in Section 5.1, likewise the discussion of the two learner surveys in Section 5.2.

An evaluation requires a UEM and a set of criteria. Various approaches exist for evaluating usability and effectiveness of educational software and web-based learning environments, for example, Albion [1] and Ardito et al. [3]. Squires and Preece [17] were pioneers of criteria for investigating learning technologies. They adapted Nielsen's [14] usability heuristics by integrating usability with learning issues, generating a set of principles for 'learning with software'. These heuristics for inspecting educational software form the basis of the criteria used in the present study.

## 5.1 Squires & Preece's Heuristics for 'Learning with Software'

Using the concepts of cognitive authenticity, contextual authenticity and socio-constructivism, Squires and Preece [17] converted Nielsen's classic usability heuristics to eight criteria that integrate usability and learning factors for predictive evaluation of educational software prior to use. Six of them (slightly amended) were used in the present study, supplemented by Criteria 9 and 10 [6], generating a set of criteria appropriate for analysing e-learning tutorials by predictive heuristic evaluation and by user questionnaire surveys after use of the application:

1. *Match between designer & learner models*: Does the application represent cognitive tasks in ways that support the development of a learner model consistent with the designer model?
2. *Navigational fidelity*: Evaluators should consider navigation structures, aesthetics, and the effectiveness of the representation.
3. *Appropriate levels of learner control*: This relates to the balance between learner control, self-direction, customization, consistent protocols, and system responsibility.
4. *Prevention of peripheral usability errors*: There is a relationship between domain complexity and error prevention. Although cognitive errors are part of the learning process, peripheral usability-related errors should be anticipated and avoided.
5. *Understandable and meaningful symbolic representation*: Representation forms, symbols and icons should be appropriate; interfaces should present low cognitive demands; learners should not have to remember interaction techniques. Names of learning objects should come from the subject domain and be consistent.
6. *Personally meaningful forms of learning*: Learning should be supported by multiple representations that support different learning styles and meta-cognition. The software should be used along with other learner support materials. (Criterion 6 was not used in this research.)
7. *Cognitive error recognition, diagnosis and recovery*: Cognitive errors are part of learning, but techniques such as scaffolding and bridging should be used to promote the recognition–diagnosis–recovery cycle.
8. *Match with the curriculum*: The software and the curriculum should correspond. (Criterion 8 was not applicable here, since *Karnaugh* was custom-designed for the curriculum.)
9. *Distinctive features*: Custom-built environments should have unique features to support the particular requirements of their content and context.
10. *Capacity of the system to engage learners*: E-learning environments should motivate learners and hold their attention.

## 5.2 Heuristic Evaluations by Experts

Heuristic evaluation (HE) [8, 14, 15] is an inspection technique developed by Jakob Nielsen and Rolf Molich, in which expert evaluators examine a prototype or operational system, using a set of guidelines or usability principles called heuristics. In participative AR, the designer asked peers to serve as expert evaluators of *Karnaugh*. Six evaluated it after its redesign in 2005; five of them subject-matter experts (SMEs), while one was a SME and a usability specialist, a so-called 'double expert'. Seven others evaluated it in a second HE after its release; four were SMEs and three were double experts. Of these thirteen, eleven teach various levels of Theoretical Computer Science and two are postgraduate students. Reflection on the first HE led to several responsive changes, but the second resulted in very few. In addition, a language editor was guided through the lesson, serving as a fourteenth evaluator.

The expert evaluators used the Squires and Preece criteria and based their inspection on a questionnaire similar to that used by the students (see Section 5.3). They worked through the lesson comprehensively, simulating students' activities. The main aim was to identify problems in the subject-matter, interfaces, usability and navigation. As explained, the two HEs occurred in different AR cycles, but are discussed together. Table 1 summarises the HEs, showing a decrease in the number of problems identified from forty-two in the first HE to only fourteen in the second.

Although the control and usage patterns of *Karnaugh* are based on traditional, rather behaviourist, CAI architecture, the experts agreed that they function effectively. The critiques suggested some additional functionality and minor modifications to the control structure. In response to the first cycle, some exercises and information were changed to be clearer and more useful. Usability was further enhanced, technical corrections were made, and language usage was improved.

| Nature of problem | Problems identified | |
|---|---|---|
| | 1st HE 6 experts | 2nd HE 7 experts |
| *Subject matter*:<br>Inadequate feedback to errors.<br>Further content-related explanations required. | 17 | 2 |
| *Mathematical errors*:<br>Errors in mathematical syntax.<br>Data type of input is not always validated. | 6 | 1 |
| *Usability errors/problems*:<br>Input options overlooked by designer.<br>Inconsistent use of buttons.<br>Responses that conceal text.<br>Position of cursor not adequately highlighted. | 12 | 4 |
| *Usability in terms of information*:<br>Inadequate info about operations available.<br>Distinction between functionalities for new and former users not explained at start of lesson. | 2 | 3 |
| *Control*:<br>Exit facility is unavailable while user does info sections, examples or exercises.<br>In one case, options entered could not be changed.<br>There are system restrictions in one exercise and with regard to minimisation of *Karnaugh*. | 5 | 4 |
| **Total number of problems identified** | **42** | **14** |

**Table 1: Problems identified in heuristic evaluations**

With regard to the criteria listed in Section 5.1, general opinions are summarised, not necessarily distinguishing between the two HEs:

1. *Match between learner and designer models*:
   The experts (peers) were very positive, firmly believing that the tutorial's approach and didactic content would help students to correctly comprehend the theory and applications of Karnaugh diagrams.
2. *Navigational fidelity*:
   The expert evaluators had no problems in navigating right through the tutorial, finding it to be well structured, easy to learn, and easy to operate.
3. *Appropriate learner control*:
   Over 80% of the evaluators felt in control and able to decide what to do next. Similarly, it was clear which button or menu item would give the required operation. There were a few requests for an <Escape> or <Minimise> button on each frame. During question answering and test taking, it is inadvisable for students to escape, since the didactic purpose is completion. The only control available in tuition frames and in worked examples, is <Forward>. These involve just a few sequential frames at a time and the designers felt that this should not be changed. In all other frames it is possible to return to the menu to choose a sub-menu or to exit. In the first HE two experts 'got lost', but in the second, following improvements, this did not occur.
4. *Prevention of peripheral usability errors*:
   In both HEs, two evaluators had usability problems. They requested use of the space bar in a situation that enforced use of backspace or tab keys in a certain exercise. As in de Villiers' [6] evaluation of another UNISA CAI application, some problems occurred when evaluators used operations and keystrokes familiar from other systems.
5. *Meaningful symbolic representation*:
   The symbols, icons and names were unanimously found to be appropriate and consistently used. Screens were user-friendly and did not cause information overload. One evaluator pointed out a lack of variety in the text; he noticed similar phrases used repetitively in instructions, in questions, and in feedback.
7. *Cognitive error recognition, diagnosis and recovery*:
   Cognitive errors could be recognised and corrected by using the feedback. Evaluators confirmed the value of learning from mistakes.

9 and 10. *Distinctive features and engagement*
The general feeling was that the lesson is appealing and engaging. Of the thirteen expert evaluators, eleven found the screen designs attractive. There was not consensus on the colours used. A third of the experts liked them, with the rest taking neutral positions. They all identified the significance of the soccer ball and its role in the lesson. Most felt that the soccer player provided light relief and a break from cognitive activities, although one found him irritating. General comments were positive: 'I am impressed with the smoothness of the system and the amount of work that went into it.' / 'I like it' / 'A very intensive and thorough lesson ... helpful to students'. 'It is great! Congratulations!'. An experienced double expert said, 'I rate *Karnaugh* highly in terms of learning and usability'. Moreover, he immediately grasped the significance of the spherical soccer ball as a continuous 3-D analogy of a Karnaugh diagram. He also appreciated the 'feeling of fun and relaxation' it gave to the interaction experience.

## 5.3 Questionnaire Survey among End Users (Learners)

Using Criteria 1-5, 7, 9&10 from Section 5.1, evaluation questions – two to four per criterion – were generated in the form of statements to be rated on a Likert scale. Some had open-ended sections for elaboration. Many learners are not first-language English speakers, so questions were phrased simply, using basic terminology. The final sections investigated users' attitudes towards *Karnaugh*'s distinctive features, such as the soccer theme. We do not have figures on the total number of students who used *Karnaugh*, since it was voluntary to complete the questionnaire. This study analyses responses to questions from the 34 questionnaires returned in 2006 and 28 in 2007. The 62 participants were a good representation of COS113 learners in terms of age (from 18 to 44), gender, cultural group and full-time / part-time students. Only five were using computers for the first time; 60% (2006) and 46% (2007) were simultaneously studying a programming module; 41% (2006) and 50% (2007) used computers at work.

Certain 2007 students were phoned for follow-up telephone interviews (Section 5.4) and this led to the identification of flawed data: some of them admitted they had completed the

questionnaire without first going through *Karnaugh*. Corrupt data is not uncommon in questionnaire surveys, but is seldom pinpointed. We were concerned and decided to determine the scale of the problem by phoning most of the participants. It turned out that seven of the 2007 participants had shortcut the process, but only three of the 2006 participants did this. Since the data was deliberately entered in a way that preserved anonymity, it was not possible to remove the offending questionnaires, meaning that up to 25% of the 2007 questionnaire data is flawed and up to 10% of the 2006 data. Due to the small-scale impact on this study as a whole, we continued to use this survey data. A secondary result of this occurrence is that we have obtained data relating to (un)ethical aspects.

Findings of the two surveys are reported under the Squires and Preece (S&P) [17] categories and were used to make minor responsive changes to the design and implementation, leading to V2.3 and V3.2 respectively. The 2006 and 2007 groups were subsequently compared with respect to each of the evaluation statements using Fisher's exact test at the 0.05 level of significance. Significance was attained when $p$ is less or equal to 0.05, with $p$ being the probability that the data derives from a distribution where the null hypothesis of 'no difference between groups' holds. Not all $p$-values and evaluative statements are reflected in the following tables.

**Match between learner and designer models: The way I understand the theory of Karnaugh diagrams** (Criterion 1)

Ratings about cognitive effectiveness were very positive. In both cohorts about half the students found some exercises 'really complicated', while the other half did not (evaluative statement 2 below), indicating balance within each group.

| Strongly agree | Agree | Maybe | Disagree |
|---|---|---|---|
| 1. Doing exercises in *Karnaugh* helps me understand the theory of Karnaugh diagrams. | | | |
| 2006: 14 (41%) | 14 (41%) | 5 (15%) | 1 (3%) |
| 2007: 11 (39%) | 16 (57%) | 1 (4%) | 0 |
| 2. Some of the exercises are really complicated. | | | |
| 2006: 3 (9%) | 13 (38%) | 11 (32%) | 7 (21%) |
| 2007: 3 (11%) | 2 (43%) | 6 (21%) | 7 (25%) |
| 3. With the teaching from *Karnaugh* I managed to get most exercises right. | | | |
| 2006: 6 (18%) | 19 (56%) | 6 (18%) | 3 (8%) |
| 2007: 6 (21%) | 15 (54%) | 7 (25%) | 0 |
| 4. The elaborations and explanations help me to understand how Karnaugh diagrams function. | | | |
| 2006: 15 (44%) | 15 (44%) | 3 (9%) | 1 (3%) |
| 2007: 8 (28%) | 18 (64%) | 1 (4%) | 1 (4%) |

**Navigational fidelity: Working my way through *Karnaugh*** (Criterion 2)

Responses to the evaluation statements below described the tutorial as easy to learn, easy to use, and the structural paths as easy to navigate. With respect to orientation within the environment (evaluative statement 6 below), the 2006 and 2007 groups differed marginally ($p$ = 0.068) with the 2007 participants being slightly less sure of their orientation within the tutorial.

| 5. I learned to use *Karnaugh*: | | | |
|---|---|---|---|
| **Very quickly** | **Quickly** | **Slowly** | **Could not use it** |
| 2006:9 (26%) | 17 (50%) | 8 (24%) | 0 |
| 2007:4 (14%) | 19 (68%) | 4 (14%) | 1 (4%) |

| Strongly agree | Agree | Maybe | Disagree |
|---|---|---|---|
| 6. When I use this lesson, I know what parts I have done and what I still need to do. ($p$ = 0.068) | | | |
| 2006:13 (38%) | 19 (56%) | 0 | 2 (6%) |
| 2007: 8 (29%) | 14 (50%) | 5 (8%) | 1 (3%) |
| 7. The lesson is easy to operate. | | | |
| 2006: 7 (21%) | 21 (64%) | 4 (12%) | 1 (3%) |
| 2007: 7 (25%) | 12 (43%) | 7 (25%) | 2 (7%) |
| 8. It is easy to learn how to use *Karnaugh*. | | | |
| 2006: 8 (23%) | 16 (47%) | 6 (18%) | 4 (12%) |
| 2007: 5 (18%) | 15 (54%) | 7 (25%) | 1 (3%) |

**Appropriate levels of learner control** (Criterion 3)

In general, students were satisfied. In most cases 80% or more selected Strongly agree / Agree. Only one student requested an <Exit> facility on each frame (open response after evaluative statement 12), although several expert evaluators requested this. A possible reason could be that the academics were very busy and used the tutorial between other work-related issues, while learners were more able to focus on study.

| Strongly agree | Agree | Maybe | Disagree |
|---|---|---|---|
| 11. I am in control of the lesson and able to choose what to do next. | | | |
| 2006: 8 (23%) | 20 (59%) | 3 (9%) | 3 (9%) |
| 2007: 6 (21%) | 17 (61%) | 4 (14%) | 1 (4%) |
| 12. I am able to escape whenever I am not in the process of doing an exercise. | | | |
| 2006: 3 (9%) | 23 (67%) | 4 (12%) | 4 (12%) |
| 2007: 4 (14%) | 15 (53%) | 8 (29%) | 1 (4%) |
| 13. When I want to take an action or perform an operation, it is clear which button to use or menu-item to select. | | | |
| 2006: 11 (33%) | 19 (58%) | 2 (6%) | 1 (3%) |
| 2007: 10 (36%) | 12 (43%) | 4 (14%) | 2 (7%) |

| Strongly agree / agree | Maybe | Disagree | Strongly disagree |
|---|---|---|---|
| 14. I got 'lost' and did not know where I was in the lesson. | | | |
| 2006: 2 (6%) | 1 (3%) | 19 (58%) | 11 (33%) |
| 2007: 2 (7%) | 4 (14%) | 15 (54%) | 7 (25%) |

**Prevention of peripheral usability errors: 'Types of mistake'** (Criterion 4)

This section relates to usability errors, not to cognitive errors (Criterion 7). The latter should be permitted, but usability errors and perception errors should be avoided. As was the case with the experts, some students experienced a usability problem by pressing a wrong key where the instructions clearly state that the space bar must not be used. This cannot be changed due to a system restriction, so we highlighted the instruction in V3.1. Errors identified in the 2006 open-ended section were rectified,

leading to better ratings in 2007. As occurred in the expert evaluation, quite a number of participants made mistakes by trying to use functions they knew from other systems (evaluative statement 16 below). This shows the tendency of generalisation and, within the constraints of the development environment, that designers should adhere to norms.

| Agree | Maybe | Disagree | Strongly disagree |
|---|---|---|---|
| 15. I made mistakes while using *Karnaugh*, i.e. usability problems. | | | |
| 2006: 10 (30%)<br>2007: 5 (18%) | 9 (27%)<br>7 (25%) | 12 (37%)<br>12 (43%) | 2 (6%)<br>4 (14%) |
| 16. I made mistakes because I used operations and keystrokes I know from other systems. | | | |
| 2006: 9 (27%)<br>2007: 4 (15%) | 7 (21%)<br>5 (19%) | 12 (37%)<br>12 (44%) | 5 (15%)<br>6 (22%) |

**Meaningful symbolic representation: *Symbols, icons & names*** (Criterion 5)

Although a high percentage of respondents found the screens easy to read, there was a significantly ($p$ = 0.038) stronger feeling amongst 2007 participants that 'there is too much information on the screens' (evaluative statement 19), due to six who chose the middle option, 'Maybe'. This might be due to the additional explanatory notes included in the 2007 versions (V3.1 and V3.2) or it could be due to flawed data from the invalid questionnaires.

| Strongly agree | Agree | Maybe | Disagree |
|---|---|---|---|
| 17. The screen layouts are easy to read. | | | |
| 2006: 15 (45%)<br>2007: 7 (25%) | 17 (52%)<br>17 (61%) | 1 (3%)<br>3 (11%) | 0<br>1 (4%) |
| 18. The symbols and names that represent the objects are used consistently in *Karnaugh*. | | | |
| 2006:11 (3%)<br>2007: 8 (29%) | 20 (61%)<br>16 (57%) | 2 (6%)<br>4 (14%) | 0<br>0 |
| 19. There is too much information on the screens and it confuses me. ($p$ = 0.038) | | | |
| 2006: 3 (9%)<br>2007: 3 (11%) | 0<br>6 (21%) | 18 (55%)<br>11 (39%) | 12 (36%)<br>8 (29%) |

**Cognitive error recognition, diagnosis and recovery: '*Recognising mistakes and recovering*'** (Criterion 7)

These errors differ from the usability errors of Criterion 4. Cognitive errors are part of learning. They occur due to domain complexities, misconceptions and pitfalls, and the aim of the feedback is to rectify them. The feedback obtained high praise, with around 90% choosing Strongly agree / Agree. Examples of open responses: 'It gives you the opportunity to re-evaluate your answer in order to find an alternative.' / 'I agree with the amount of feedback.'

| Strongly agree | Agree | Maybe | Disagree |
|---|---|---|---|
| 20. The feedback (system response) to incorrect answers is useful. | | | |
| 2006: 13 (39%)<br>2007: 9 (33%) | 16 (49%)<br>18 (67%) | 4 (12%)<br>0 | 0<br>0 |
| 21. The feedback to my incorrect answers helped me get it right the next time. | | | |
| 2006: 3 (39%)<br>2007: 9 (33%) | 18 (55%)<br>16 (59%) | 1 (3%)<br>1 (4%) | 1 (3%)<br>1 (4%) |

**Distinctive features, motivation and engagement** (Criteria 9 and 10)

Participants liked the aesthetics and the colours, and most enjoyed the informal theme of the soccer player and his ball.

| Strongly agree | Agree | Maybe | Disagree |
|---|---|---|---|
| 22. The screen designs are attractive. | | | |
| 2006:7 (21%)<br>2007:9 (32%) | 20 (61%)<br>15 (54%) | 5 (15%)<br>4 (14%) | 1 (3%)<br>0 |
| 23. I like the colours in *Karnaugh*. | | | |
| 2006: 7 (21%)<br>2007: 7 (25%) | 20 (61%)<br>14 (50%) | 5 (15%)<br>7 (25%) | 1 (3%)<br>0 |

| 24. Throughout *Karnaugh*, you encountered the soccer player and ball.<br>What do you think the ball represents? Explain your answer and give your opinion of this theme and logo. | | | |
|---|---|---|---|
| **Karnaugh diagr**. (correct) | **To reach the goal** (acceptable) | **Other** (incorrect) | **No answer** |
| 2006:16(47%)<br>2007: 6 (22%) | 3 (9%)<br>2 (7%) | 5 (15%)<br>9 (32%) | 10(29%)<br>11(39%) |
| 25. The activities of the soccer player (you may choose more than one option): | | | |
| **Are fun** | **Give me a break** | **Make no difference/irrelevant** | **Are irritating** |
| 2006: 20<br>2007: 12 | 15<br>11 | 5<br>5 | 1<br>1 |

With relation to the soccer ball theme, 47% of the 2006 participants grasped that it represented a Karnaugh diagram, but in 2007 only 22% did. In open responses, learners commented on the soccer activities: 'It allows a student to associate *Karnaugh* with a fun activity.' / 'Gives you a break and clears your mind so that you can concentrate better on the tasks.' / 'When I was confused, the soccer player also showed that confused face. This took away a lot of stress because you are not the only one confused. He is like a buddy that shares the same emotions'. On the other hand, one stated 'Because of time constraints I did not pay much attention to the activities.' An interesting comment: 'Since we are hosting the 2010 World Cup, I thought that the syllabus is also having soccer fever'!

With regards to the tuition, there were varied comments: '*Karnaugh* is a brilliant tool. I personally feel that all CAI lessons should include more examples.' / 'It is useful to be able to choose between theory and the different difficulty levels of examples.' / 'I was impressed by the colours used to explain things.' / With regard to the feedback to incorrect answers: 'It boosted my confidence in tackling the assignment.' / 'Helps you to note other points you didn't understand when doing the theory – lets you think out of the box.' One student commented: 'I was not satisfied with the navigation buttons because they are not everywhere throughout the lesson.' and another '*Karnaugh*'s theory part needs more explanations.' Some learners were extremely positive: 'I was actually reluctant to stop using it (presented so nicely that it is a pleasure using it).' / 'The 'game' in the end was extremely exciting and motivating, I

attempted each question seriously and it paid off.' / 'Brilliant work indeed.'

### 5.4 Interviews

Telephonic interviews were done with a sample of seven students on issues not fully addressed in the questionnaire. They were a representative, heterogeneous group in terms of gender, age and full time/part-time status. The interviews were semi-structured, in that core questions were asked and notable or unanticipated responses were followed up.

*Did you use the multi-option feature that lets you choose between information, examples, basic exercises or complex exercises*?

Participants responded positively, acknowledging the utility of the feature. One said that she mainly used the <Forward> button so as to do all the activities, but used the multi-option when she needed to 'refresh her memory' on specific aspects. This confirms its value in helping students use *Karnaugh* in different ways at different times, e.g. in practicing exercises before exams.

*What do you think of the CAI experience overall*?

The lesson was said to be 'interesting', 'helpful', 'fun' and 'challenging'. One student particularly enjoyed working through the examples; another found the exercises 'very practical, they gripped my attention'. A student having his first-ever encounter with CAI was surprised to find how user-friendly it was.

The interviews highlighted the value of *Karnaugh* as supplementary tuition material. Issues not resolved by the study guide alone, were solved by CAI. We confirmed the value of multiple means of presentation and different perspectives on Karnaugh diagrams. One student found that the soccer theme and animated round ball continually reminded him that Karnaugh diagrams are 3-dimensional, which is not always perceived from printed representations.

*Tell us about problems you encountered in using* '*Karnaugh*'.

Very few problems emerged. One student found it so helpful that she asked for the background and teaching content to be extended even further.

*How did Karnaugh contribute towards your answering of exam questions*?

Participants were positive that the e-learning tutorial contributed to comprehension of Karnaugh diagrams. One specifically stated how it had helped with 'making the groups in the diagrams'. Another described how she had originally struggled with the diagrams, but that the CAI tutorial had been 'a practice session before the exams'. Another said that he would not have been able to do that section in the examination at all, were it not for the CAI experience.

### 5.5 Conclusion

The answers to the two research questions are concisely summarised:

1. How can the design, redesign and evaluation of e-learning be supported by an action research (AR) approach?

The action research approach to design, development and multiple evaluation is described explicitly in Section 3 and is the implicit 'golden thread' throughout Sections 4 and 5. The researcher-designer took participative ownership of the study, and AR demonstrated its value as input was continuously fed into the cycles in the form of corrections and improvements to *Karnaugh*. The iterations gave rigour to the study. *Karnaugh* evolved through five variants, culminating in a version which is virtually free of problems and of great value to its target group.

2. What kind of findings emanate from the various evaluation methods?

The S&P [17] evaluation framework has high utility in evaluating CAI (whereas newer frameworks are aimed more at Web-based learning). The criteria served effectively to identify both the educational worth and usability of *Karnaugh*, as well as issues that required correction or refinement.

Different UEMs played complementary roles. There were two heuristic evaluations by experts – one that eliminated pre-release problems and another done on V1.3. They proved to be a fast and effective means of finding and correcting issues in e-learning applications.

Interviews with students elicited valuable spontaneous information that is difficult to obtain from rigid surveys. In this case, the interviews also unveiled unethical completion of questionnaires by some participants who did not have the required background.

User-based questionnaires supplemented the data from HEs, but were less valuable in pin-pointing problems. Their worth lies in the positive responses and qualitative open-ended data confirming that *Karnaugh* is on track in supporting its users. The flawed data encountered does not invalidate the overall value of this multi-faceted longitudinal study, since it relates to one aspect only. The lesson to be learned is that questionnaire administrators should take explicit measures to guard against such inconsistencies. For example, a questionnaire could specifically enquire up-front whether subjects have done the required background work, and if not, request that they proceed no further.

The participants of 2007 achieved slightly higher marks in the exam questions relating to *Karnaugh* than the participants of 2006 ($p$ = 0.766; 57.1% versus 55.6%). Overall, the percentage of passed-over-written for the entire exam was 59.43 for the 2006 examination group and 52.26 for the 2007 group. In general the 2006 cohort was stronger than the 2007 cohort.

This study shows that CAI lessons developed at UNISA, such as *Karnaugh* with its good usability, high interactivity, insightful tuition, and excellent feedback to exercises, has a role to play in the world of the Web and Net.

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