Computers & Education 103 (2016) 16–27

Contents lists available at ScienceDirect

Computers & Education

journal homepage: www.elsevier.com/locate/compedu

The effectiveness of brain-compatible blended learning material in the teaching of programming logic

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ARTICLE INFO

Article history:
Received 8 September 2015
Received in revised form 8 September 2016
Accepted 17 September 2016
Available online 20 September 2016

Keywords:
Interactive learning environments
Programming and programming languages
Pedagogical issues
Teaching/learning strategies

ABSTRACT

Blended learning is an educational approach which integrates seemingly distinct educational approaches, such as face-to-face and online experiences. In a blended learning environment the classroom lectures can, for example, be augmented with learning material offered in a variety of technologically delivered formats. There exist extensive evidence that a blended learning approach which mixes face-to-face and online learning materials is substantially more effective than using only face-to-face educational methods. However, in order to be effective, blended learning course material should still be designed and presented according to sound pedagogical principles. This article presents the results of an experiment to augment the teaching of fundamental programming logic based on the pedagogical principles underpinning brain-compatible learning materials via e-learning delivery mechanisms. The research uses both qualitative and quantitative methods. Results show promise for this use of brain-compatible material in a blended learning context.
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1. Introduction

Universities today have to constantly balance the need to maintain high educational standards with the need to both optimise the throughput of students in the educational system and maximise the number of students serviced by the educational institution. This is especially true in the South African context where there is increasing pressure on higher education institutions to facilitate greater access in addition to increasing throughput rates (Boughey, 2003). Increased class sizes at universities usually also mean that lecturers have less time available for giving students personal attention (Blatchford, Bassett, & Brown, 2011). Teaching large university classes can lead to a situation where it is nearly impossible to personalise the learning experience by providing one-to-one interaction and/or hands-on experience (Bersin, 2004). While most university students are adults who already have well-established learning styles and preferences and who also often have to manage multiple responsibilities and demands on their time (Clapper, 2010; Materna, 2007), the educational approach followed in the classroom may not necessarily match their pre-existing learning styles and preferences, or allow for the multiple demands on a student's time.

One way to augment traditional classroom education and to provide support for both a greater variety of learning styles and more flexibility in terms of time spent learning is the use of blended and/or e-learning material (Bersin, 2004). Blended learning is an educational approach which integrates seemingly distinct educational approaches, such as face-to-face and

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http://dx.doi.org/10.1016/j.compedu.2016.09.008
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online experiences (Means, Toyama, Murphy, Bakia, & Jones, 2009). In a blended learning environment the classroom lectures can, for example, be augmented with learning material offered in a variety of technologically delivered formats. Research has found extensive evidence that shows that a blended learning approach which mixes face-to-face and online learning materials is substantially more effective than using only face-to-face educational methods (Means et al., 2009). However, in order to be effective, blended learning course material should still be designed and presented according to sound pedagogical principles (Heinze, 2008; Torrao & Tiirmaa-Oras, 2007).

This article presents the results of an experiment to augment the teaching of fundamental programming logic based on the pedagogical principles underpinning brain-compatible learning materials via e-learning delivery mechanisms.

The remainder of this paper is structured as follows: Section 2 provides background information to place the objectives of the study in context. Section 3 provides a brief overview of brain-compatible learning principles. The research process followed during this study is discussed in Section 4. Section 5 provides a detailed discussion of the research experiment and its design. Section 6 presents the results and a discussion of these results. The limitations of the work are discussed in Section 7 and Section 8 concludes the paper.

2. Background

In the field of Information Technology, programming is considered a core skill as programming concepts are used in almost all core courses (Lunt et al., 2008). This skill encompasses "Fundamental Programming Constructs and "Algorithms and Problem Solving (Lunt et al., 2008, p. 32). Both of these core conceptual areas thus form part of the curriculum for the National Diploma: Software Development as offered by the Information Technology Department at the Nelson Mandela Metropolitan University (NMMU, 2012).

Students studying towards the National Diploma: Software Development qualification get their first exposure to the above-mentioned core areas in the subject Development Software I. This initial exposure is then reinforced in their second year by the subject Technical Programming I, which specifically focuses on the reinforcement of the problem-solving strategies and algorithm design skills introduced in their first year. The skills learnt in this subject are considered essential for the analysis and design of information technology business solutions (Lunt et al., 2008). It is thus vital for these students to master these skills.

However, this subject has a very high drop-out and failure rate. During 2011, for example, only 44.4% of students who initially enrolled for this subject were successful. Apart from the obvious negative impact such a high failure rate has on student retention and throughput, it should also be noted that even students passing the course often have very low marks. Since this subject teaches one of the fundamental skills needed in this field of study, increased understanding of the concepts taught would be also be beneficial for the overall success of students in this qualification.

The high failure rate associated with the subject Technical Programming I can possibly be attributed to several factors. These factors include, but are not necessarily limited to, the following:

- Large class size
  - At the start of 2011 the theory classes consisted of a single group of 192 students.
  - Practical classes during 2011 contained an average of 40 students per practical class group.
- The complexity and technical nature of the subject matter
- The possible lack of related and foundational logical problem-solving skills of the students entering the course
- Language problems – many of the students are not English first language speakers
- A lack of high quality peer support

As mentioned earlier, it might be possible to address, or partially address, several of the above-mentioned problems by introducing e-learning-based material into the curriculum for this subject. Such material should not serve to replace the lecturer's function but rather augment teaching. However, such material would have to be based on a pedagogically sound educational approach. One such an approach is brain-compatible learning (Jensen, 2008; Materna, 2007; McGeehan, 2001).

Brain-compatible learning is an approach to education which is based on the underlying biology of learning instead of simply following traditional practices (McGeehan, 2001, p. 9). This educational approach stems from a combination of neuroscience and educational psychology and was first made possible by advances in brain imaging during the 1990s (McGeehan, 2001). The term "brain-compatible learning" was first coined by Leslie Hart in 1983 in his book *Human brain and human learning,* to refer to education designed to match settings and instruction to the nature of the brain, rather than trying to force (the brain) to comply with arrangements established with virtually no concern for what this organ is or how it works best (McGeehan, 2001, pp. 7–8). Brain-compatible, or brain-based, learning is not a formalised education approach or "recipe for teacher", instead it provides a "set of principles and a base of knowledge and skills upon which we can make better decisions about the learning process" (Jensen, 2008, p. xiii).

Brain research has shown that humans literally grow new dendrites and neural connections every time they learn something (Lombardi, 2008). Knowing which educational activities are the most effective in stimulating such growth allows educationalists to create material, leveraging the way the brain naturally learns. Through such knowledge the educational process could be significantly enhanced for most students (Taylor, 2008, p. 43).

Since their inception, brain-compatible learning techniques have been used extensively in classroom environments. Many practical guidelines given for the adoption of brain-compatible principles are specific to classroom environments (Smilkstein, 2003; Taylor, 2008). However, some studies also focus on the incorporation of such principles in the design of computer-based education materials (Bradshaw, 2003). The effectiveness of brain-compatible approaches has, despite some criticisms, been proven (Winters, 2001). It could be argued that most of the brain-compatible learning principles identified by previous researchers can also be used in the implementation of e-learning-based learning materials. However, little or no research exists relating specifically to the use of brain-compatible principles to design e-learning-based material to assist students in learning algorithm and problem-solving skills.

As mentioned above, brain-compatible learning does not provide a structured recipe for educational design, but rather consists of a variety of principles that the instructional designer can use to make better decisions about learning. Many of these principles apply specifically to classroom instruction, for example principles dealing with the effect of ambient lighting on learning (Jensen, 2008, pp. 57–58). However, it has been shown that some of these principles can also be successfully applied in an e-learning environment (Reid & Van Niekerk, 2014). A full discussion of all the possible brain-compatible learning principles, and the evidence for their effect, falls outside the scope of this paper. However, in order to place the principles used in the intervention in this study within context, the next section will provide a brief overview of these principles. The principles specifically used during this research will be discussed in more depth in Section 5.3.

3. Brain-compatible learning principles

As mentioned before, brain-compatible learning stems from a combination of educational psychology and neuroscience. Various brain-compatible learning principles were derived through observing actual physiological changes in the brain (neuroscience) as a result of specific educational interventions (educational psychology). The use of many of these brain-compatible learning principles in education is not new. According to Erlauer (2003) every successful teacher already uses certain brain compatible principles effectively. However, as mentioned above, the direct evidence demonstrating the physiological effect that using these principles have on the learner's brain was only made possible due to recent advances in brain imaging technology.

Currently, no single authoritative list or taxonomy exists that describes and encompasses all known brain-compatible learning principles, instead various authors present different principles (Fogarty, 2009; Jensen, 2008; Materna, 2007; Sousa, 2006; Craig, 2003; Smilkstein, 2003; Caine & Caine, 1991). There is, however, a significant overlap between the principles presented by these authors. The following list serves as an overview of principles identified during the current study:

- There is no long term retention without rehearsal (Fogarty, 2009; Jensen, 2008; Materna, 2007; Smilkstein, 2003; Sousa, 2006).
- Short, focused learning activities are best (Jensen, 2008; Sousa, 2006).
- Learning Is enhanced by challenge and inhibited by threat (Fogarty, 2009; Jensen, 2008; Craig, 2003; Caine & Caine, 1991).
- Emotions affect learning (patterning). (Fogarty, 2009; Materna, 2007; Craig, 2003; Smilkstein, 2003; Caine & Caine, 1991).
- Learning involves both focused attention and peripheral perception (Learning experiences should be multifaceted) (Fogarty, 2009; Jensen, 2008; Materna, 2007; Craig, 2003; Caine & Caine, 1991).
- The brain has a spatial memory system and a set of systems for rote learning (The brain has separate implicit and explicit memory systems) (Fogarty, 2009; Caine & Caine, 1991).
- The brain simultaneously perceives and processes parts and wholes (Fogarty, 2009; Craig, 2003: Caine & Caine, 1991).
- Learning engages the entire physiology (A healthy lifestyle promotes learning) (Fogarty, 2009; Jensen, 2008; Materna, 2007; Craig, 2003; Caine & Caine, 1991).
- The brain is a parallel processor (Multitasking) (Fogarty, 2009; Jensen, 2008; Craig, 2003; Caine & Caine, 1991).
- Learning is embedded in natural and social settings (Fogarty, 2009; Caine & Caine, 1991).
- Each brain is unique (Fogarty, 2009; Jensen, 2008; Craig, 2003; Caine & Caine, 1991).
- The search for meaning is innate (Fogarty, 2009; Jensen, 2008; Craig, 2003; Caine & Caine, 1991).
- The search for meaning occurs through patterning (Fogarty, 2009; Jensen, 2008; Craig, 2003; Caine & Caine, 1991).
- Learning always involves both conscious and unconscious processes (Fogarty, 2009; Materna, 2007; Caine & Caine, 1991).
- Learning with specific context is best (Craig, 2003; Jensen, 2008).
- Learning is the process of forming novel neural networks or patterns (Craig, 2003; Smilkstein, 2003).
- Novel patterns can only form as extensions of existing patterns (Craig, 2003; Materna, 2007; Smilkstein, 2003; Sousa, 2006).
- Learners need to recognize and connect patterns by themselves (Learning only happens from what is actively, personally, and specifically experienced) (Craig, 2003; Jensen, 2008; Materna, 2007; Smilkstein, 2003).
- Learners should be given choices to accommodate different learning styles (Lessons should be multifaceted) (Craig, 2003; Jensen, 2008; Materna, 2007).
- Learning must apply to real life experiences (context) of learners (Craig, 2003; Jensen, 2008; Materna, 2007).
- Immediate feedback amplifies learning (Craig, 2003; Jensen, 2008).

- Learning is collaborative and influenced by interactions with others (Materna, 2007).

Some of the principles listed above would be difficult to control for in a blended learning, or even in a classroom, environment. For example, knowing that a healthy lifestyle promotes learning is something that can be communicated to students but that cannot necessarily be controlled by the instructional designer. Similarly, the understanding that learning is the process of forming ‘novel neural networks or patterns’ can enhance a learner's understanding of how his/her own brain works, and can even be used to combat certain fixed mindsets that could have a negative impact on learning, but does not otherwise practically affect instructional design (Smilkstein, 2003).

However, despite the fact that some of these principles would be difficult to incorporate in an e-learning environment, many of these principles **could** still be applied during the design of e-learning based instructional material (Reid & Van Niekerk, 2014). In this study the researcher selected specific principles based on his personal perception of how easy it would be to incorporate these principles into the design of the intervention. It should be noted that the intention of the researcher was not to include all possible principles, but rather to include as many as was feasible to do within the constraints of limited time and resources. A full discussion of the above principles, and evidence for their effect, is considered outside the scope of this paper. However, Section 5.3 of this paper provide a more in depth overview of the specific principles that were selected for inclusion in the design of the research intervention, and how these principles were applied to this intervention's design.

4. Research process

The primary purpose of this research was to investigate the effectiveness of brain-compatible blended learning material in the teaching of programming logic. This research stemmed from a desire to address an observed problem in the subject Technical Programming I, which forms part of the foundational education of software development students in the School of Information and Communication Technology (ICT) at the Nelson Mandela Metropolitan University. As noted earlier, this subject has a very high failure rate which, in the researcher's opinion, could be partially ascribed to the large number of students in a typical class for this subject. As it has been suggested that augmenting traditional teaching with brain-compatible blended learning material could have a positive effect on student learning, this study was conducted to test this premise.

The researcher performed three literature studies during the initial phases of this research. The first literature study aimed to determine what *brain-compatible* education is, and what principles an educational intervention would have to adhere to in order to be considered *brain compatible*. Sections 2 and 3 of this paper provide a brief overview of these principles. Specific principles selected for use in the study are further elaborated on in Section 5.3 of the paper. A second literature study was conducted to determine what *blended learning* is. In the current study all concepts used and explained in the intervention were already covered in the classroom. The e-learning based intervention was thus used to augment the traditional classroom instruction, which is characteristic of a blended learning approach, as discussed previously in Section 2. Finally, a literature study was conducted in the field of programming education. The aim of this third literature study was to identify a set of fundamental programming logic skills and related learning objectives that would be appropriate as a basis for this study. This third study was used primarily to identify appropriate problems to use as a basis for student tasks during the intervention. The selected tasks are discussed in Section 5.2. Based on the combined results of the three literature studies the researcher created an educational intervention which incorporated *brain-compatible learning* principles into an *e-learning* medium to teach fundamental programming logic. This resulting e-learning based material should still be considered a blended learning approach, because the material was still only used to *augment* the prior classroom lessons which covered the same underlying concepts as the intervention. It is important to note that the selected brain-compatible principles used in this study were applied only to the design of the e-learning components of the intervention and that no such principles were purposefully applied during the related classroom instruction.

An instrument to measure the effect that the use of this intervention would have on student motivation to learn was then developed by adapting an existing instrument to the specific needs of this research study. In addition, the researcher created a second instrument in the form of an assessment exercise to measure the participants’ fundamental programming logic skills. The intervention was then tested experimentally.

Firstly, permission to conduct the experiment to test the effect of the educational intervention was obtained from the institutional research ethics committee, the management of the School of ICT, and the lecturer responsible for the subject. Subsequently, students from the Technical Programming I subject were recruited to participate in this experiment. The experiment was then conducted in accordance to all the requisite ethical guidelines. The experiment was conducted over a two-week period during the normal practical sessions for the subject. The participating students were subdivided into an experimental group and a control group but did not know which of these groups they belonged to. After initial division into these groups some of the students were allowed to swap places with other students in a different group in order to accommodate their individual needs. Students were also given the option not to participate in the experiment at all, an option which several students exercised.

During the first practical session the control group was given specific concepts to study and tasks to complete in a format that was consistent with the usual way in which practical material was presented in this course. This practical session was only attended by control group students. The material was made available in an e-learning medium to augment work already covered in class, hence blended learning, but did not adhere to any of the identified brain-compatible learning principles.

During the second week the experimental group was given the brain-compatible material and tasks. These tasks were also presented using an e-learning medium and covered the same fundamental programming concepts as those assigned to the control group but the tasks were designed in such a way as to engage the students according to selected brain-compatible principles.

After both groups had completed their assigned practical exercises the students wrote a non-summative class test, in the form of the designed instrument, which evaluated their understanding of the concepts covered by the work presented during the experiment. After the completion of the experiment all students, including those in the control group and those who had elected not to participate in the experiment at all, were given unlimited access to the brain-compatible material. Subsequent to this, the students were asked to complete the questionnaire that had been adapted to measure motivation to learn. This concluded the experimental phase of the research. However, in order to answer the research question "What effect will the use of brain-compatible e-learning material have on the student achievement?" the researcher subsequently also analysed the performance of the participants in the formal summative semester tests for the subject. It should be noted that these semester tests did not form part of the experiment and were set, administered and graded by the lecturer for the subject, who had no prior knowledge of the specific material that was covered in the experiment.

5. Methodology

The work in this article was conducted on the basis of a pragmatic philosophy. The author does not prescribe to either a strict positivist or a strict interpretive viewpoint. Instead, the author believes that methods should be chosen on the basis of their suitability for the specific task at hand. The various elements comprising the research intervention itself were developed using a *design science* approach and the author adhered to all the guidelines for this research strategy, as presented by Hevner, March, Park, and Ram (2004). Both qualitative and quantitative data-generating instruments were used. More details about these and other methodological considerations are given in subsequent subsections.

5.1. Sample and setting

This study was conducted in the Information Technology Department of the School of ICT at University X. The participants for the study were specifically selected from the subject Technical Programming I (PRT1000), which forms part of the National Diploma: Software Development qualification. The sample used was both *convenient* and *purposive*. A convenience sample is a sample that is "available to the researcher by means of its accessibility" (Bryman, 2012, p. 201). The Technical Programming I class was *convenient* for the researcher because he is a staff member in the same department at the School of ICT and thus had easy access to this class. Further, the researcher used a *purposive* sampling approach where participants were specifically selected "so that those sampled are relevant to the research questions that are being posed" (Bryman, 2012, p. 418).

The researcher has lectured in this specific subject in the past and was thus thoroughly familiar with the subject material, and the specific problems students in this subject might experience. Because the researcher no longer personally lectured in the subject it was easier for him to ensure that he did not influence the results unwittingly. As discussed in Section 2, this subject teaches fundamental algorithmic problem-solving skills to software development students. However, despite the first-year level of the subject content, the students in the Technical Programming I class are second-year students who have already passed the subject Development Software I, which is a prerequisite subject for Technical Programming I. These students are thus already familiar with basic programming syntax. This made it easier for the researcher to focus on the underlying concepts specifically related to fundamental programming *logic*.

Lectures for the Technical Programming I subject consist of both theoretical and practical sessions. Practical sessions are conducted in a computer laboratory and consist of three consecutive lecturing periods of 45 min each. The research experiment took the form of an intervention during two of these practical sessions in August 2013. For this experiment, the participating students were subdivided into an experimental and a control group. At the time the experiment was conducted students in the Technical Programming I class had already written two semester tests for the subject. The researcher used the results of these earlier semester tests to ensure that the experimental and control groups were as balanced as possible. These groups were created in the following way:

1. A year-to-date average mark was calculated for each student based on the average mark the student had received for the two prior semester tests (major summative assessments).
2. The class list for the subject was sorted in ascending order in terms of the above year-to-date mark.
3. Students from this class list, sorted according to the year-to-date marks, were allocated alternately to the experimental group and the control group.

Students were not told whether they were allocated to the control group or the experimental group; instead they were allocated a specific practical session to attend, with the students attending the first of the two practical sessions (12 August 2013) being used as the control group ($n = 68$). Subsequently, attendees of the second practical session (19 August 2013) were used as the experimental group (n = 46). It should be noted that, in compliance with research ethics constraints, student participation in the research was completely voluntary and students were allowed to choose not to participate during any stage of the research. Several students chose not to participate, especially during the second session, which resulted in an uneven number of students in each of these groups. No data from students who chose to exercise their right to not participate were included in either the experimental or the control group data. However, as will be shown during the analysis of the data, these uneven numbers of participants had no measurable effect.

5.2. Intervention

As mentioned before, the intention of this research was to determine whether the use of brain-compatible material in an e-learning format would have a beneficial effect on student learning in the subject Technical Programming I. In order to test this, an intervention was designed based on two tasks that the researcher considered to be appropriate for students in this subject. The first task selected was to write the code for a given computer sorting algorithm. The use of computer sorting algorithms to teach programming logic is a well-established feature of many algorithm courses (Geller & Dios, 1998; Kordaki, Miatidis, & Kapsampelis, 2008). This was thus considered an ideal task for this intervention. The second task selected was to write a program to simulate the children's game “Fizzbuzz”. This task was chosen because it requires a clear understanding of basic decision structures in programming logic, but still requires very little time to complete. It is often used as a quick test by recruiters interviewing programmers for precisely these reasons (Atwood, 2007).

5.2.1. Control group intervention

A practical exercise based on the above tasks was created for students in the control group of this experiment. The students had to firstly create a program that would use a sorting algorithm to sort a given list. The students were provided with a step-by-step description of the required algorithm, as well as a link to relevant Wikipedia content that provides additional explanation for this sorting algorithm. Secondly, the students were provided with a step-by-step description of the FizzBuzz game and were then required to write code that would produce the desired response for this game for the first 30 natural numbers. Once again students were given a link to appropriate Wikipedia content that might have been of help should they have required further clarification. For both these tasks the students were required to submit the completed source code at the end of the practical session. This format is typical for *normal* practical exercises in this course. It should be noted that these tasks were created to augment prior classroom lessons regarding algorithmic problem solving, and that all programming constructs needed were already covered in the physical classroom. Furthermore, because all the instructions and the additional explanatory material provided were in a digital format and delivered via a web interface these tasks could thus be described as a blended learning approach. However, the material was not designed according to any specific pedagogical approach and none of the brain-compatible elements that were purposefully used in the design of the intervention were used in the construction of this control group practical task.

5.2.2. Experimental group intervention

For the experimental group a variety of material was created that adhered to previously identified criteria for brain-compatible e-learning material. A full discussion of the principles used, and how the elements discussed in this section adhere to these principles, is supplied in the next subsection. Firstly, an interactive PowerPoint presentation was created for each task. Each presentation firstly explained the purpose of the specific task, and then provided the student with both the source code that would solve the problem, and a schematic representation of the programming logic used. Further representations were given displaying the current value of all the relevant variables defined in the code, which were currently within the range of the problem, as well as a trace table showing the prior value of all variables. Fig. 1 presents a screen shot of the sorting algorithm presentation. The student then had to step through the code one statement at a time whilst observing the value changes caused by each line of code. As can be seen in Fig. 1, the current line of code to be executed during this step-through mode is highlighted in yellow. This interactive presentation occasionally requires the student to answer a question about the expected effects of the current line of code. Such a question for the fizzbuzz task is shown in Fig. 2. Based on the answer to the questions posed, the student receives immediate positive or negative feedback, as well as an explanation as to why the answer is deemed correct, or incorrect. Fig. 3 shows such immediate feedback during the fizzbuzz task. It is important to note that no marks were allocated for answers to these questions in order to keep this part of the intervention non-threatening.

Secondly, in addition to the interactive presentations for each of the tasks, a third presentation was made explaining in detail how the concept of a modulus (remainder) to test whether or not one number is divisible by another is used in the fizzbuzz code. Thirdly, two narrated (audio) explanations were created, each consisting of a pencast video in pdf format. These pencasts was recorded using a livescribe electronic pen and present the viewer with a discussion consisting of both handwriting and recorded audio, both recorded using the livescribe pen, in which the researcher first explains and discusses the concept of one number being a divisor of another and then how this is used in the fizzbuzz task and what.

the common pitfalls are to watch out for in this task. Each pencast can be viewed by the student as a static image of the recorded handwriting, or listened to as just an audio file, or (ideally) viewed as a pencast video. If viewed as a video the handwriting, and accompanying audio narration is synchronised and played back at the same pace at which the researcher

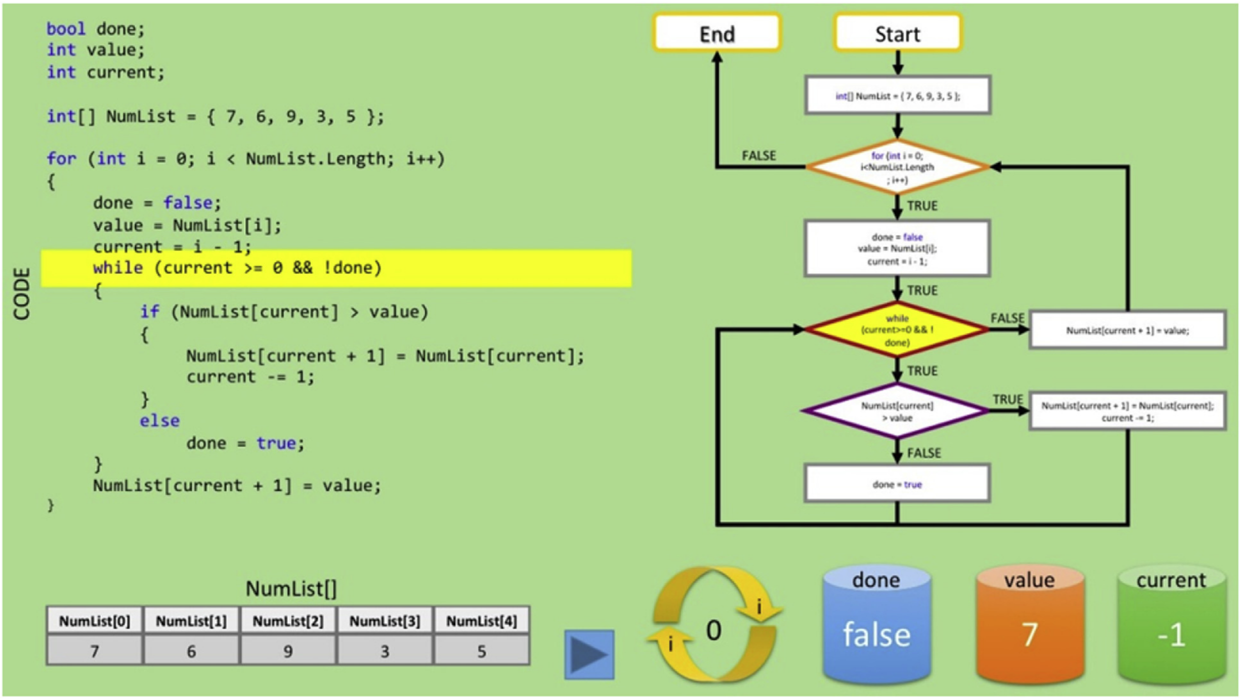

Fig. 1. Interactive sorting algorithm presentation.

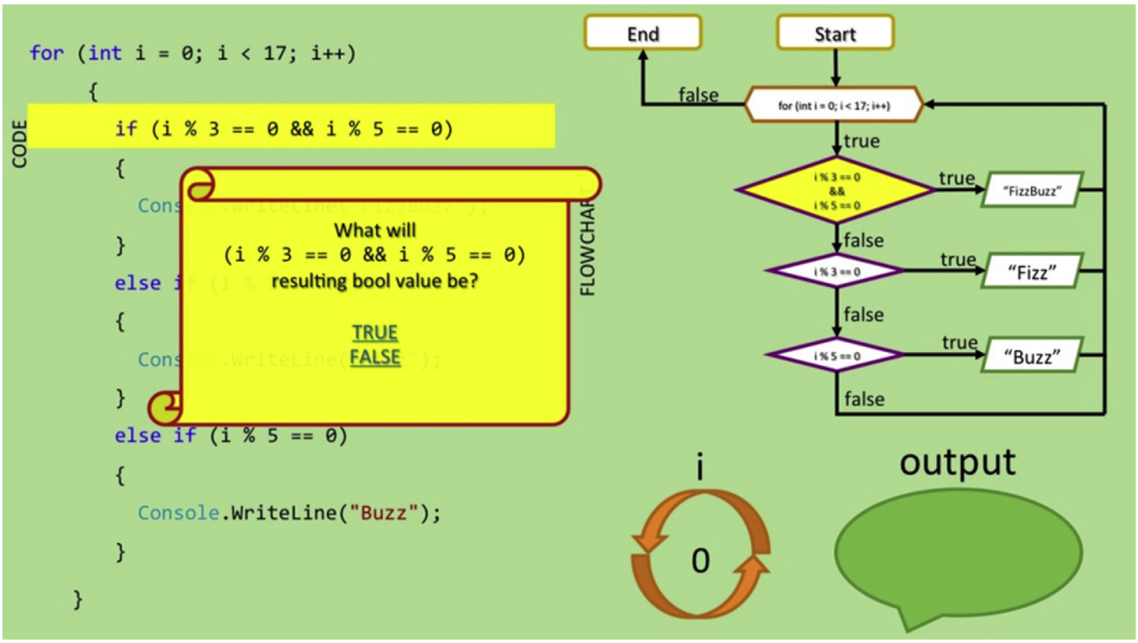

Fig. 2. Interactive question during fizzbuzz code execution.

recorded the pencasts. When viewed as a video, or played as an audio only file, the first pencast had a duration of 5 min and 49 s, whilst the second pencast duration was 3 min and 50 s.

Fourthly, an interactive discussion of the sorting algorithm was created in the form of a moodle lesson. This lesson used the same colour scheme as the PowerPoint presentations but required more student input and had an associated formative assessment mark allocated for each question asked. Fig. 4 shows an example question from this moodle lesson.

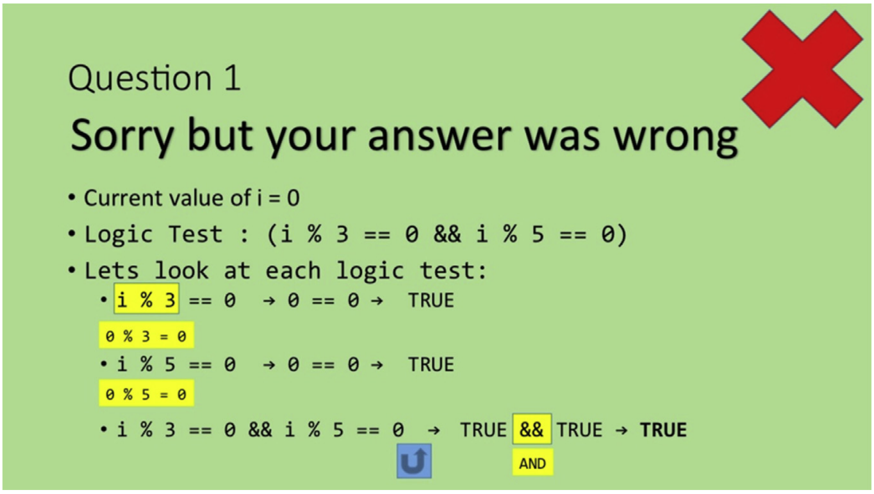

Fig. 3. Example of immediate interactive feedback during fizzbuzz task.

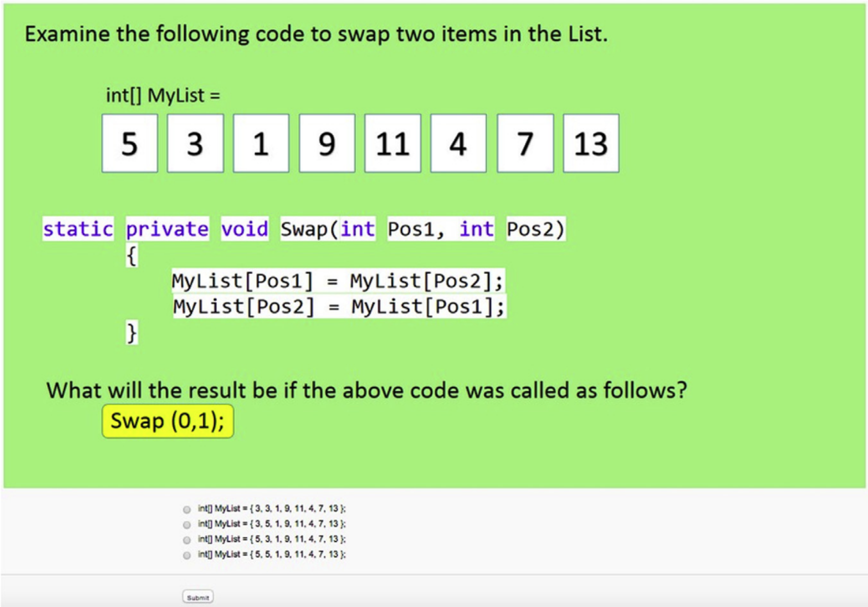

Fig. 4. Example question from moodle lesson.

Finally, a short summative quiz consisting of three questions, each requiring the student to once again apply the studied underlying principles was created. This added the need to once again perform the task, this time under the stress of what he/she believed to be a summative assessment.

5.3. Brain-compatible principles used in the intervention

Collectively, the above elements provided an intervention that adhered to several brain-compatible principles:

- The intervention consisted of several small tasks, each of which took between five and 10 min to complete. Jensen (2008, p. 29) recommends limiting cognitive activities to periods of five to 10 min each. This is because “learning is best when focused, diffused, and then focused again” (Jensen, 2008, p. 28).
- Animation and colour changes were used to highlight currently executing lines of code and to draw the student's attention to important features. According to Jensen (2008, p. 55), one should “attract the brain with movement, contrast, and colour

changes. Our visual system is designed to play close attention to those elements because they each have the potential to signal danger".

- Colours chosen included the use of yellow to highlight the currently executing code, because yellow is the first colour the brain distinguishes, and green as a background colour, because green encourages productivity (Taylor, 2008).
- Several forms of feedback were used to encourage learning. Firstly, the learner received feedback after answering the questions included in the moodle quiz and lesson. Secondly, the interactive presentation provided continuous visual feedback in the form of changing the values of internal code variables during the simulated walkthroughs. Lastly, the presentation also provided detailed instantaneous feedback on the answers provided to questions during the interactive simulations. According to Jensen (2008, p. 195) "the best feedback is immediate, positive, and dramatic".
- "Learning involves both focused attention and peripheral perception" (Fogarty, 2009). Thus, even whilst attention is focused on a specific task, the brain is aware of other peripheral sensory (visual, kinaesthetic, etc) inputs (Fogarty, 2009). The interventions firstly supplied additional sensory inputs in the form of visual representations during the simulated tracing of source code. Thus, whilst concentrating on the code, the student's peripheral attention would note that variable values change according to the logic dictated by the code statements. Secondly, the narrated discussions provided both written illustrations of concepts and narrative audio explanations.
- The brain processes parts and the whole simultaneously (Fogarty, 2009). According to Banikowski (1999), people learn "by organizing new information into hierarchies and organizing information so that the relationships between isolated bits of information can be detected". The simulations were thus designed so that the learner could perceive the entire algorithm in the form of both code and the flow diagram provided, while simultaneously highlighting the sub-part currently in context. Insight into the underlying values of variables was also given both for the whole and the currently executing code. This also engages both visual and verbal faculties which encourages meaningful learning (Lombardi, 2008).
- It is important to provide both multiple opportunities and sufficient time to allow learners to grow knowledge structures through sufficient, specific practising and processing of any newly learnt or modified concepts (Smilkstein, 2003, p. 128). Repetition of newly learnt concepts is extremely important to prevent the "pruning" or removal of newly grown synaptic connections in the brain that might be deemed unneeded (Lopez & Alipoon, 2001). All the activities in the intervention thus repeated the same underlying fundamental programming logic concepts, namely, decision structures that compare two choices and, for each choice, choose a specific action based on underlying data values, and looping structures that control code iteration through a predetermined list of values.

It is important to note that the brain-compatible intervention still had exactly the same underlying tasks as the normal practical exercise that the control group had to complete. The tasks were simply structured in a more brain-compatible format.

5.4. Data-generating instruments

As mentioned earlier, this research used both qualitative and quantitative data. A qualitative questionnaire was completed by the students after the experiment had been completed. This instrument was derived from one previously used by Du Plessis (2010) and was used to measure student motivation to use the brain-compatible material. To generate quantitative data, this research made use of the standard summative assessments, known as semester tests, used in the subject. The subject is a year course and has four such semester tests during the course of the year. As mentioned before, the researcher had no involvement in either the setting or the grading of these assessments. The subject lecturer, who set and graded the assessments, also had no involvement in the research experiment. The researcher did create an additional assessment that was specifically intended to measure the immediate effect of the intervention. However, statistical analysis of the results of this additional assessment was not significant and, for the sake of brevity, a full discussion of the design of this assessment will not be presented here.

5.5. Data collection

Data were collected using the above-mentioned data-generating instruments. Data collection happened as follows:

- Firstly, before the intervention took place the students had already completed two of the summative semester tests for the subject. As discussed, the results of these two tests were used to assign the students to either the experimental or the control group for the intended experiment.
- Secondly, the results of the additional assessment that the researcher designed were collected immediately after the intervention was completed.
- Thirdly, the qualitative questionnaire was completed by students who used the brain-compatible intervention material. This included students from both the experimental group and those of the control group who had voluntarily accessed the brain-compatible material after the conclusion of the experiment. These answers were collected using Surveymonkey (www.surveymonkey.com). Since participation was voluntary, some of the students who were invited to complete this

survey did not do so. In addition, many of the control group students never exercised their right to access the experimental material.

- Fourthly, the results of the final two semester tests were collected at the end of the academic year. The first of these tests was written one week after the intervention and the second was written nine weeks after the intervention.

5.6. Data analysis

The quantitative data were sent to the unit for statistical support for analysis and the results were interpreted on the basis of this statistical analysis. The results for the qualitative questionnaire were analysed using the reports provided by Surveymonkey and all interpretation of these reports was done on a qualitative basis. The results are discussed in Section 5.

5.7. Ethical considerations

This research project received approval from the Nelson Mandela Metropolitan University research ethics committee (Ref H12-EDU-ERE-031). In order to adhere to research ethics requirements all participation in the research was voluntary in nature. Students who did not form part of the experimental group were given full and unrestricted access to the same material used in the brain-compatible intervention directly after the completion of the non-summative test that was intended to measure the intervention's effect and had such access for the remainder of the calendar year during which the intervention took place.

5.8. Validity and reliability

As mentioned earlier, the qualitative instrument was adapted from an existing instrument that was designed to measure student motivation to learn. The quantitative data were analysed by the statistical support unit of the University X. Where appropriate, specific statistics are mentioned in the next section during the discussion of the results.

6. Results and discussion

The results of the analysis of the four semester tests written by the students are shown in Table 1. As can be seen from this table, the differences between the experimental group and the control group were negligible prior to the intervention (Tests T1 and T2). As mentioned before, the combined scores of T1 and T2 were used to sort students, who were then assigned to one of the two groups based on alternating allocation. However, some students were allowed to move between groups for the student's convenience, and not all students assigned to the experimental group chose to participate in the entire exercise. All statistics related to students who opted out during the experiment were thus not included.

The results of test T3, which was written one week after the intervention, show that the experimental group had a mean score that was 6.95% higher than the mean score for the control group. However, this result is not statistically significant. The results for test T4, which was written nine weeks after the intervention, show that the experimental group had a mean score that is 8.82% higher than the mean score of the control group. This result is statistically significant using a 95% confidence interval. The Cohen's d value for this is 0.42. Cohen's d is an effect size that indicates the standardised difference between two means and is calculated as the difference between the means divided by the standard deviation. The value of 0.42 is smaller than 0.5 and the difference between the means, despite being significant, should thus be interpreted as being of small practical significance. This also indicates the need for using a larger sample size in future experiments.

Based on the above, it is the researcher's opinion that the intervention did positively influence the participants' future performance in the subject and that this positive effect took a few weeks to fully materialise. This is possibly due to the fact that the intervention focused on very fundamental logical constructs which, if better understood, would transfer to other aspects of programming competency.

In addition to the above quantitative results, the qualitative questionnaire was answered by a total of 74 of the participants. Of these students, 74% indicated that they had found the learning to be different from their normal class experience and 78% indicated that they had enjoyed this type of learning. Most, 90%, indicated that they thought that other learners would enjoy this form of instruction. Some of the learners (19%) indicated they would prefer this type of learning to their normal classroom

Table 1
Results of statistical analysis of semester test T1 to T4 results for brain-compatible education (BCE) group ($N = 45$) vs control group ($N = 66$); $df = 109$.

	Mean BCE	Mean control	t-value	p	Std. Dev. BCE	Std. Dev. Control
T1	58.20	58.76	−0.14	0.8873	18.78	21.28
T2	58.44	57.18	0.34	0.7378	18.69	19.97
T3	77.56	70.61	1.56	0.1214	20.77	24.44
T4	69.84	61.02	2.16	0.0327	15.97	23.98

learning, whilst the majority (70%) indicated they would prefer using both their normal learning and this type of e-learning. Only 10% indicated they would prefer only their normal classroom type of learning. Other findings indicated the following:

- Students could relate to the examples used (71% positive response).
- The material was easy to navigate (79% positive response).
- Having multiple resources for each concept taught helped the learner to understand the concept being taught (75% positive response).
- Students did not believe they had learnt more about the programming topics by completing the e-learning modules than through other approaches to learning (52% of students responded neutrally or negatively).

Many of the open-ended responses that were allowed for additional comments reflected that the students really enjoyed the fact that the e-learning material allowed them to work at their own pace. Most significantly, in the researcher's personal opinion, is the fact that 86% of the learners gave a positive response to the question "When you have learnt and completed an e-learning module, do you feel like you have gained knowledge which is yours?"

Overall, the researcher believes the experimental results showed that the use of brain-compatible e-learning material could have a positive impact on the teaching of fundamental programming logic. However, the study still had the same limitations and more work is needed in future to confirm these results.

7. Limitations of study

The biggest limitation of this study was the relatively small sample size, and the fact that only a single intervention was made. This contributed to the results being of low practical significance (Cohen's $d = 0.41$). Future research should attempt to use a larger sample size and, if possible, the experiment should be repeated as part of a longitudinal study over several years. The biggest challenge in such a study would be to not inadvertently disadvantage students who form part of a control group in such research. During this study great care was taken to encourage control group students to also make use of the blended learning material after completion of the intervention. However, access logs in moodle showed that most of them did not make use of this opportunity and many who did only did so briefly prior to answering the qualitative questionnaire.

8. Conclusion

The demand for higher education has never been greater than it is today. Many educational institutions worldwide are, in part, responding to this demand through the increased provision of e-learning material to augment traditional classroom instruction. However, such e-learning material still needs to adhere to some pedagogical principles. This study has shown that e-learning material which adheres to brain-compatible education principles shows promise in the teaching of fundamental programming logic to software development students.

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