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Full Length Research Paper

Visualization skills and their incorporation in biology curriculum

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Many graduates of various levels and disciplines appear unable to practically apply their knowledge in problem solving situations. However, few education systems are adopting modern education practices such as visualization skills that intrinsically motivate and engage learners and are at the same time flexible enough to consider students' aspirations and interests. Such systems make learning more relevant, meaningful and enjoyable to the learners and improve exit performances. In such a system, the role of the teacher is that of a facilitator and not instructor. The purpose of this study was to identify three-dimensional (3D) visualizations that could aid comprehension and perception of cytoplasmic structure, geo-referenced graphical data and understanding of spatial relationships in Biology. A qualitative research approach was used to ascertain from university lecturers (n = 13) what convictions, beliefs and experiences they have had with their students that related to the use of visualization skills. Skills most required included interpretation of 2 and 3D structures as well as their rotation in space. A survey was also carried out among cell biology first year students (n = 145) and second year students (n = 45) of the School of Life and Environmental Studies at the University of Natal in order to precisely determine aspects of three-dimensionality and visual skills suspected to cause conceptual difficulties. Quantitative data analysis (the non parametric Mann-Whitney U - Wilcoxon Test at a confidence level of 0.05) showed that the most deficient skills in the learners included pattern folding (projecting 2D material into 3D objects), orientation of form (identifying 3D objects that are oriented differently) and rotation (identifying 3D objects from top and front views). These findings corroborate qualitative analysis of lecturers' opinions and convictions. An educational computer game is proposed with the aim of ameliorating these problems. It is recommended that visualization skills should be incorporated into the Biology curriculum for all undergraduate students within the first year of the course.

Key words: Three-dimensional (3D), visualization skills, quantitative data analysis.

INTRODUCTION

Nations world over have come to grips with the fact that investment in education is necessary and cannot be allowed to regress to obsolescence. Since technology is rapidly embracing various aspects of our daily activities, many countries have dedicated a lot of resources to technology education. However, the use of computer technology in educational systems is not clearly understood. Also, while technology is available in the well-developed countries, little funding or support is provided for such developments in less developed countries. While this is true in developed countries, awareness, especially in the use of computers in education is lamentably low in the less developed countries

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(Amory, 1997). Worldwide, education appears to be in crisis. The ability of existing educational approaches to deliver knowledge appears unable to adequately assist learners to acquire skills and values appropriate to a rapidly changing world. These concerns are stimulating growth in the application of modern educational technology. There is evidence that a change is taking place which involves placing students (and technology), rather than instructors (and curricula), at the centre of educational practice (Greening, 1998).

In an examination of how using computer tools can alter education fundamentally, House (1979) suggested that successful integration of Information Technology (IT) in schools requires awareness of the role of the teacher and the existing curriculum. This is because different curriculum considerations imbedded in individuals or groups of people influence their educational practices. The issue of contention here is that teachers ought to change their general instructional approaches of monopoly and rigidity to more open models that would give the learners considerable control and choice over their learning endeavours. In South Africa, as well as in other developing nations, use of computers in education is minimal even though the trend is changing to accommodate more widespread use of computers. In 1994, only one country in sub-Saharan Africa, South Africa, had direct access to the Internet. At the end of 1996, only 11 countries had local access, but by May 1999, only Congo (Brazzaville), Eritrea and Somalia were still without local Internet services. However, both Congo and Eritrea recently announced plans to establish services. Ghana alone has three private Internet service providers (Jensen, 1999). In Kenya, for instance, an educator acknowledged the fact that computers have become a necessity, expressing concern and disappointment that most educators themselves are computer illiterate. According to him, institutions have to embrace information technology if they are to survive in the 21st century. He predicted that by the year 2020, knowledge will be doubling every 73 days and called for planning for the curriculum of the next century. Imminent redundancy of the text books currently in use is foreseen and teaching methods that currently predominate could be obsolete. Schools of the next century would be "schools without borders" (Daily Nation, 1998).

There are several major constructivist recommendations for teaching and instruction that would allow for incorporation of computer technology in order to improve education. Constructivists postulate that instruction should take place in rich contexts that reflect the real world and are as closely related as possible to contexts in which this knowledge would subsequently be used, thereby maximizing motivation and transfer (Underwood and Underwood, 1990). These authors also believe that carefully planned and sequenced instruction tends to be decontextualized and promotes inert knowledge. This mode of learning would also restrict multiple perspectives that would be important for transfer of knowledge. Therefore, while content domains can be predetermined, carefully sequenced objectives within these domains should be avoided. Instead, these perspectives should be encouraged and promoted by providing for collaborative and cooperative learning (Underwood and Underwood, 1990).

There appears to be superabundance of students who do not apply what they learn in school and who can answer with words but are not able to apply their knowledge. Some students also appear to consider certain educational practices irrelevant but have little or no option on practices. Constructivism is argued as a resolution for these problems and could be viewed as an important evolutionary step in understanding learning and teaching, rather than a paradigm shift (Scott et al., 1987). One of the basic constructivist assumptions is that empowerment should be intrinsically motivating because it serves as human need to seek information and solve problems. Applying this assumption to technological innovation, many researchers view acceptance and integration of technology as an evolutionary process. If technology is presented judiciously, individuals grow more comfortable and proficient in it and hence become more innovative in applying it to self directed learning (Collins, 1991; Saye, 1997).

Prior research conducted by the Bioped Research Unit (School of Life and Environmental Sciences, University of Natal, Durban, South Africa) has identified that many undergraduate students experience problems relating to visualization. This project focused on the identification of specific three dimensional and perceptual weaknesses in learners, with the aim of proposing solutions to the problems. Since the visualization skills are applicable to other disciplines, educational standards could consequently be improved by the inclusion of specific learning tools that foster the development of 2D and 3D visualization.

Currently, there is a popular requisition for use of computers in the process of teaching and learning. This effort is not evenly spread in global terms, and, as a result, assessment of its general impact is problematic and uncertain. It is however apparent that a measure of confusion about effective roles computers can play in education abound. Amory (1997) attributed the apparent failure of Computer Based Education (CBE) to a number of reasons, including technical difficulties in building suitable networking and administrative structures to capacitate CBE, placement of inappropriate user-interfaces and the inadequacy of artificial intelligence to provide mechanisms that could make computers more responsive to learner needs. He also pointed out that there is limited research into the use of CBE, and, failure to execute appropriate educational pedagogies that could support CBE. In order to improve educational standards, it would be beneficial to investigate and reform these trends (Welsh, 1993; Amory, 1997).

Even though the computer is proving to be the best tool of the current technological age, it should be viewed with objectivity. The use of this technology has reached a level in its development which requires a critical examination of prior predictions concerning the range of educational tasks it would be able to perform with marked efficacy.

The objectives of the study were to:

(a) identify particular visualization skills that learners require in order to learn effectively,

(b) assess the viability of incorporating the visualization skills (as a separate course) into the undergraduate biology curriculum to enhance and improve learner skills and exit outcomes, and

(c) design and develop an educational game aimed at training learners in the use of three dimensionality and general problem solving skills.

RESEARCH METHODOLOGY

It has been argued that 2 and 3D visualization skills are required to understand many basic biological concepts. To design appropriate curricula that could allow for the development of such skills, it was necessary to determine which skills academics thought were required; to evaluate student 2 and 3D perceptions skills; and to investigate the use of computer tools in developing such skills. The 'Dark Light' software (maze) to be developed to address learners' perceptual problems would incorporate a series of 3D scenes where learners would navigate through different levels of difficulty and solve an educational problem before moving to the next level.

The first part of the investigation used face-to-face interviews with members of the School of Life and Environmental Sciences, University of Natal, Durban, to determine attitudes and opinions of experts for the requirement of 2 and 3D visualization skills in biology students. A qualitative research approach was used to gain insights into deeply embedded convictions and opinions that underpin university lecturers' reflective persuasions. This method was preferred because of its unique qualities of flexibility, ability to probe in order to clear misunderstandings, to create rapport, to elicit unanticipated or unexpected responses that would suggest novel hypotheses, and the added advantage of being able to observe non-verbal communication in forms of auditory and visual cues (Patton, 1980).

All academic members (experts) of the School of Life and Environmental Sciences (n=13) accepted to be interviewed after receiving an electronic message requesting their participation in the process. The electronic message included a covering letter indicating the scope of the face-to-face interview and some brief explanations of terms to clarify any unfamiliar concepts. The interviews took place in the offices of the participants. Time schedule for the interviews fell between 09.00 and 16.00 h spread over a period of three weeks. Interview duration ranged between 20 and 70 min. This enabled a candid and in-depth interview culminating in a clear perspective of the convictions, experiences and opinions of the lecturers regarding the use of visualization skills in teaching and learning.

Each interview was audio-recorded and then transcribed into QSR NUD*IST 4.0 (Qualitative Solutions and Research Non-Numerical Unstructured Data Indexing Searching and Theorizing). Authentic names of the participants are used in this text as none objected. QSR NUD*IST 4.0, a software for qualitative data analysis, was used for data management and analysis. To identify and quantify student 2D and 3D visualization skills, a questionnaire was designed.

The sample for questionnaire administration was drawn from the University of Natal. Students from the Department of Biology (n = 190). Purposive sampling method was used. Of importance were prior experiments and findings by Biological Pedagogy (Bioped) Research Group that Biology students exhibit conceptual difficulties in various topics. This was to establish observed problem areas with the aim of proposing corrective measures.

The sampling units arrived at was as a result of the need to examine particular causal linkages in question between learners' perceptual behaviour and age. It was felt that in order to establish the stage at which visualization skills would be most beneficial to learners, it would be appropriate to observe learners at the formative stages of the undergraduate course.

A multiple-choice questionnaire adapted from standardized tests from the Human Sciences and Research Council was used (Appendix). This was divided into three sections. The tasks in Part A required students to correctly match figures to identical rearranged ones. In Part B, students were expected to identify blocks of cubes with similar ones presented or viewed, from different angles. Part C exercises involved mentally folding/bending flat objects along indicated/dotted lines to come up with correct 3D objects.

The test was administered to first year Cell Biology students (n = 145) and second year Cell Biology students (n = 45) of University of Natal, Durban. A zero score indicated an incorrect response and a score of one a correct one. The total sum of scores was regarded as percentages, sorted in ascending order and ranked. The results of each section were consequently compared, in relation to level of learning/academic year of students and gender using cross-tabulations and the Mann-Whitney U - Wilcoxon Test.

RESULTS

Assessment of the viability of incorporating visualization skills into the curriculum

To examine the extent to which 3D visualization skills can improve learner perception of various concepts, the interviews revolved around the most effective stage to introduce a specific skill in an undergraduate course; influence of prior experience or exposure to 3D visualization environments; and viability of introducing the skills/techniques to a course as a measure to enhance and improve student performance and learning skills.

Twelve out of thirteen respondents strongly felt that it would be helpful to introduce visualization skills at the beginning of the undergraduate course (93%). Since remedial courses may be necessary in later stages if they are identified, some respondents suggested that the skills do not have to be necessarily limited at the first year level. On exposure to 3D visualization environments, 93% of the respondents agreed that prior experiences do have an impact on the learners' visual skills. Even though some commented that the vast majority of their students were drawn from urban areas, it was unanimous that exposure, and, the extent to which learners interact with their environment impact a great deal on the development of the visual skills. Rather than being taught separately, twelve of the thirteen respondents suggested that introduction of visualization skills to a course should

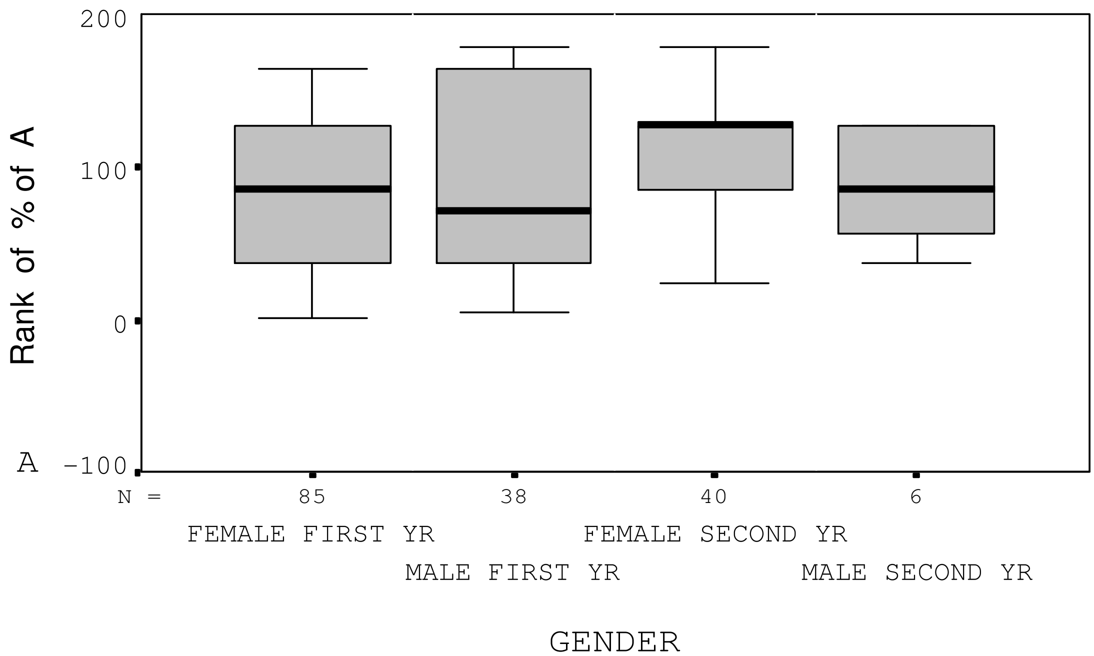

Figure 1. First year and second year biology student performance in Part A (identifying rearranged objects), showing gender categories.

take an integrated approach (93%).

The general feeling (77%) was that visualization skills are necessary and should be introduced as an integrated course at the early stages of the undergraduate curriculum. This was ultimately arrived at when the respondents were prompted to give a general comment at the end of the interview. A typical response was:

> "I think it's a wonderful idea, and I think that the sooner we can get into the work the better because I do believe that biology students need to be able to visualize in 3D, and I do think there's an enormous deficiency there".

Identification of particular visualization skills required by learners

The non parametric Mann-Whitney U - Wilcoxon Test was used to determine statistical differences between students of first and second year groups and gender with respect to 3D visual skills (at a confidence/critical level of 0.05). Analyses of responses related to pattern matching (Part A) showed no significant difference between first year female and male students ($p = 0.8180$) and between second year female and male students ($p = 0.1192$). On the other hand, analysis of Part B showed that male first year students performed better than female first year students ($p = 0.0052$). There was no significant difference between female and male second year students ($p = 0.1297$). Results of Part C showed that female first year students did not perform as well as their male counterparts ($p = 0.0345$).

In order to determine how students perceive objects presented in different perspectives and orientations, a Three Dimensionality Test was presented to the first and second year Biology students. Section A of the test required students to find and match figures to rearranged identical ones. Figure 1 shows the results of gender comparisons.

Female students performed better than male students in tasks that required identification of rearranged objects (Figure 1). Female second year students had a higher mean rank of percentages compared to first year students, even though they were skewed below 100% mark. The mean was however still higher than for the other categories. Second year male students had a slightly higher mean compared to first year male students even though their percentage ranks appeared more skewed above the mean than that of the first year students (Figure 1). These results suggest females are better at pattern matching than males. However, it appears that more males are able to complete this task successfully than do females.

Section B required students to identify 3D cubes oriented in different angles (Figure 2).

From Figure 2, it is observable that, comparatively, female first year students had the lowest mean rank, even though most of them were concentrated around the 100% mark. Second year female students had a higher

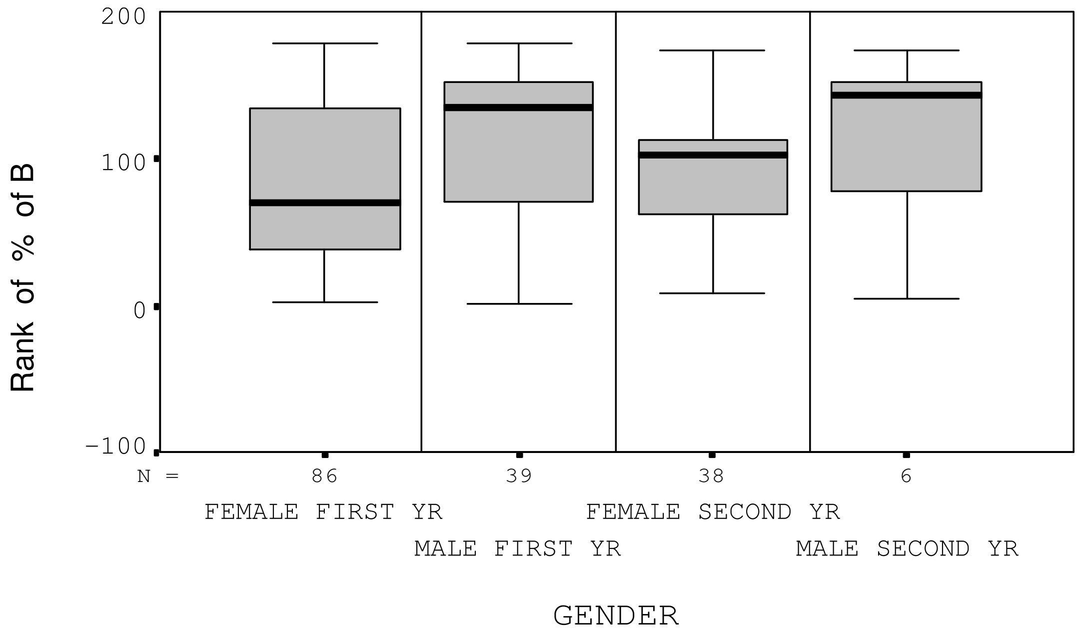

Figure 2. First and second year biology student performance in Part B (identifying 3D objects oriented differently), showing gender categories.

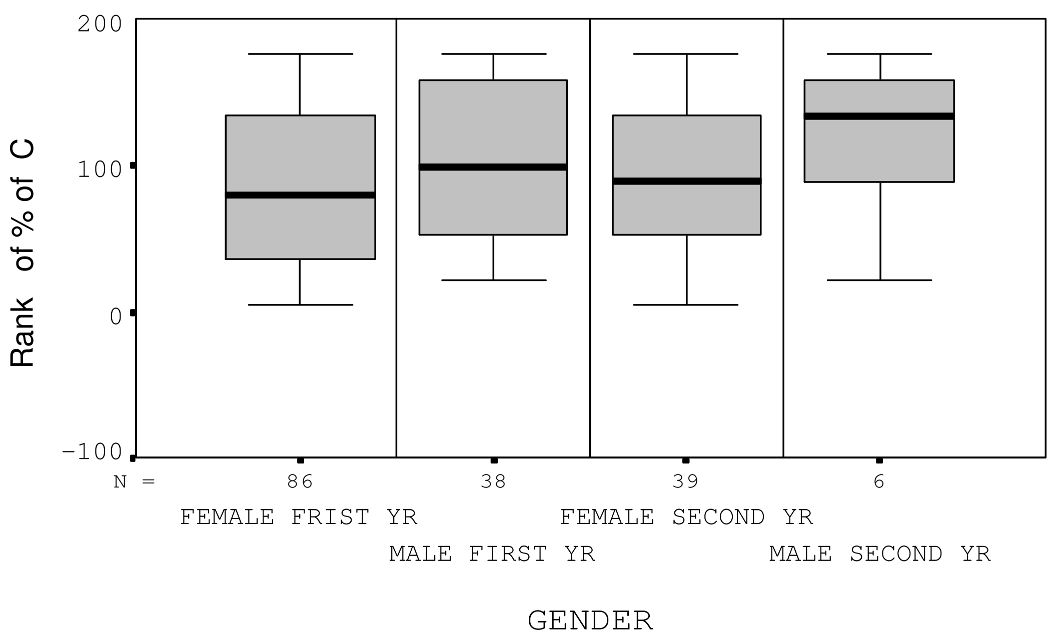

Figure 3. First and second year biology student performance in Part C (folding two dimensional objects into three dimensional ones), showing gender categories.

mean than first year female students. This was however lower than that of first and second year male students. Second year male students appeared to have slightly better averages than first year male students. Therefore, male students appear to be better able to mentally rotate 3D objects in space.

In Section C, students were asked to mentally configure 2D objects, folding along perforated lines to form three-dimensional objects. This was examined with regard to gender and race categories (Figure 3).

In tasks involving folding 2D objects into 3D objects (Figure 3), male first year students had a better mean rank

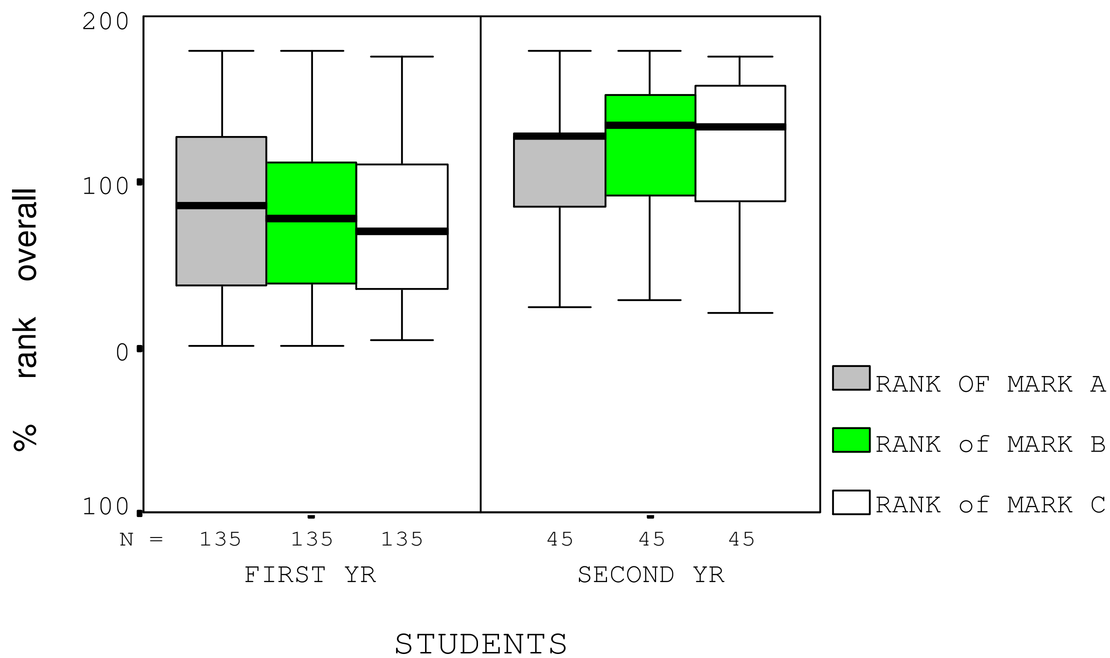

Figure 4. Overall performance of first and second year students, showing Parts A, B, C.

than their female first year counterparts. Female second year students had a lower mean than male second year students. The male second year students had the highest mean rank even though they clustered more below the 100% mark. These results suggest that male students were better at folding 2D objects into 3D objects than were female students.

In entirety, it can be observed that students in second year performed better than students in first year in all of the three sections of the test (Figure 4). It is observable from Figure 4 that students of the second year had higher averages in all the three sections of the 2D and 3D tests.

It can be concluded that learners were confirmed to exhibit deficiencies in use of 3D visualization skills. This was also in line with other experiments carried out by other members of Bioped Research Unit. Redress was therefore imperative. The most prevalent skills lacking included rotation of 3D images in space, identification of 3D objects projected from 2D images and pattern completion. These would be considered in the design of a learning resource that would be proposed to address them. It also confirmed findings from interviews done with lecturers as the areas of difficulty observed by them concurred with the ones identified from students.

Conclusions and implications

Restructuring and formulating an innovative curriculum framework obligates a networked commitment between all stake-holders that would be affected by the anticipated changes. In the same line, this study attempted to underscore the close coordination between academic staff and administrators, subject experts and learners to arrive at a consensus in order to incorporate a course into an existing curriculum (Hartman and Warren, 1994). A similar approach was adopted successfully at University of Wolverhampton, London in 1993 (Jenkins and Walker, 1994) even though emphasis here was on independent study by students together with staff-away days. Emphasis of this project was laid on close consultation with students and lecturers while identifying visualization problems that learners have and designing a computer based educational game to address these problems. This study reveals that there is a need to re-consider our assumptions about educational practice. Learning is seen to be constructed as a process of enculturation whereby appropriate skills, knowledge, beliefs, and values are acquired through participation in a learner centred environment (Lauzon, 1999). This constructivist approach should however be carried out in conjunction with (traditional) instructivism so as to accommodate interpersonal and intrapersonal learner needs.

Approaches to instructional design within the context of mediated education ought to consider a curriculum framework that is suitable. Technology, especially computers, if used in the right way, can lead to improved educational standards. CBE should therefore not be used in isolation, but should be supplemented with other interactive media resources. Conclusively, the educa-tional computer game (Dark Light) designed in this project was found to be effective in heralding learner perception of concepts otherwise incomprehensible.

Another conclusion of this study is that visualization skills, particularly orientation and rotation of 2 and 3D images in space, are necessary and this implies that they should be incorporated into the curriculum. Even though remedial cases were identified (that is, learners who did not perform well in the tests), it is suggested that the skills be introduced to all of the students in the first year of the undergraduate programme. This is because even learners who did well altogether may not have done well in all aspects of 3D visual skills. Assessment of the use of the educational software (Dark Light) developed in this project is also recommended. Since the educational game was proposed to be included in the curriculum, its impact needs to be evaluated.

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APPENDIX

3D visualization skills incorporation in biology undergraduate course:
University lecturers' interview

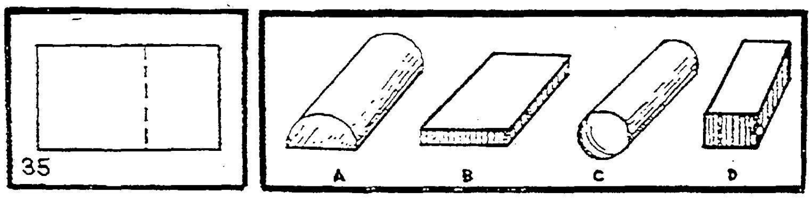
This interview seeks to obtain information and insights from university lecturers concerning their opinions and convictions about use of 3D visualization skills in teaching and learning. The ultimate goal is to design educational resources and strategies that are possibly more effective and embrace Computer Based Education. Your involvement in the project is invaluable and will take us a long way in realizing the goal.

Interview Questions:

1) Arc visualization skills/techniques necessary to aid instruction in topics you teach?
2) Do your courses require visualization skills? If so, could you define the types of visualization skills you think your students require? FOR EXAMPLE, pattern folding (projecting 2D material into 3D objects); orientation of form (identifying 3D objects that are oriented differently); rotation (identifying 3D objects from top and front views); pattern matching (identifying objects that are rearranged); pattern completion (arranging images to form a full picture).
3) Do students have a grasp of visualization concepts/techniques in topics you teach? 4) Do students exhibit improved/changing levels of visualization skills with age or advance in levels of learning?
5) Are there variations in levels of grasp of visualization techniques in learners of different racial backgrounds?
(6) Do you think teaching of visualization skills is transferable and would aid instruction in topics you teach?
7) Should all students learn some visualization concepts?
8) Should visualization techniques be a part of Biology course or should there be a separate course in the area'?
9) At what stage of the Biology course should visualization concepts be introduced?
10) What sorts of exercises do you think should be included in the course to improve visualization skills?

PART C
INSTRUCTIONS

These are exercises in finding objects made from pieces of metal or cardboard. In the example below, on the left is a drawing which represents a flat piece of metal. The dotted lines indicate where the metal is to be bent. On the right are drawings of four objects. In each exercise, only one object can be made by bending the metal piece. Therefore, cross out A on the answer sheet next to number 35.



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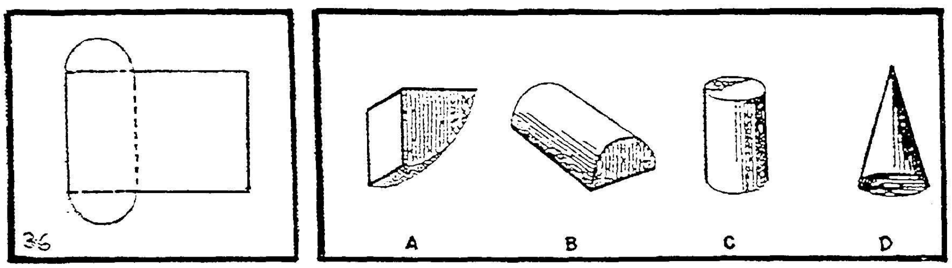

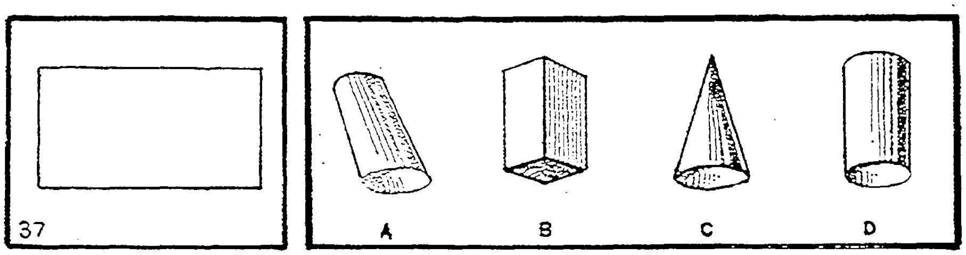

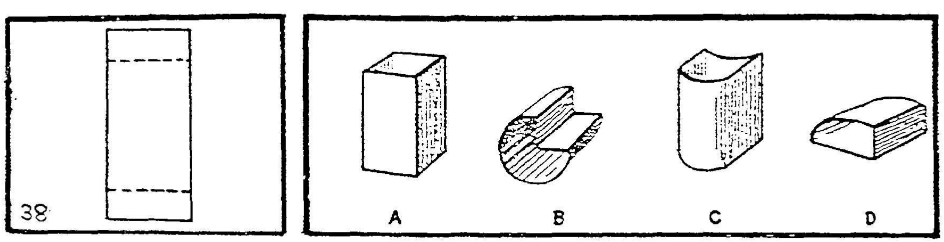

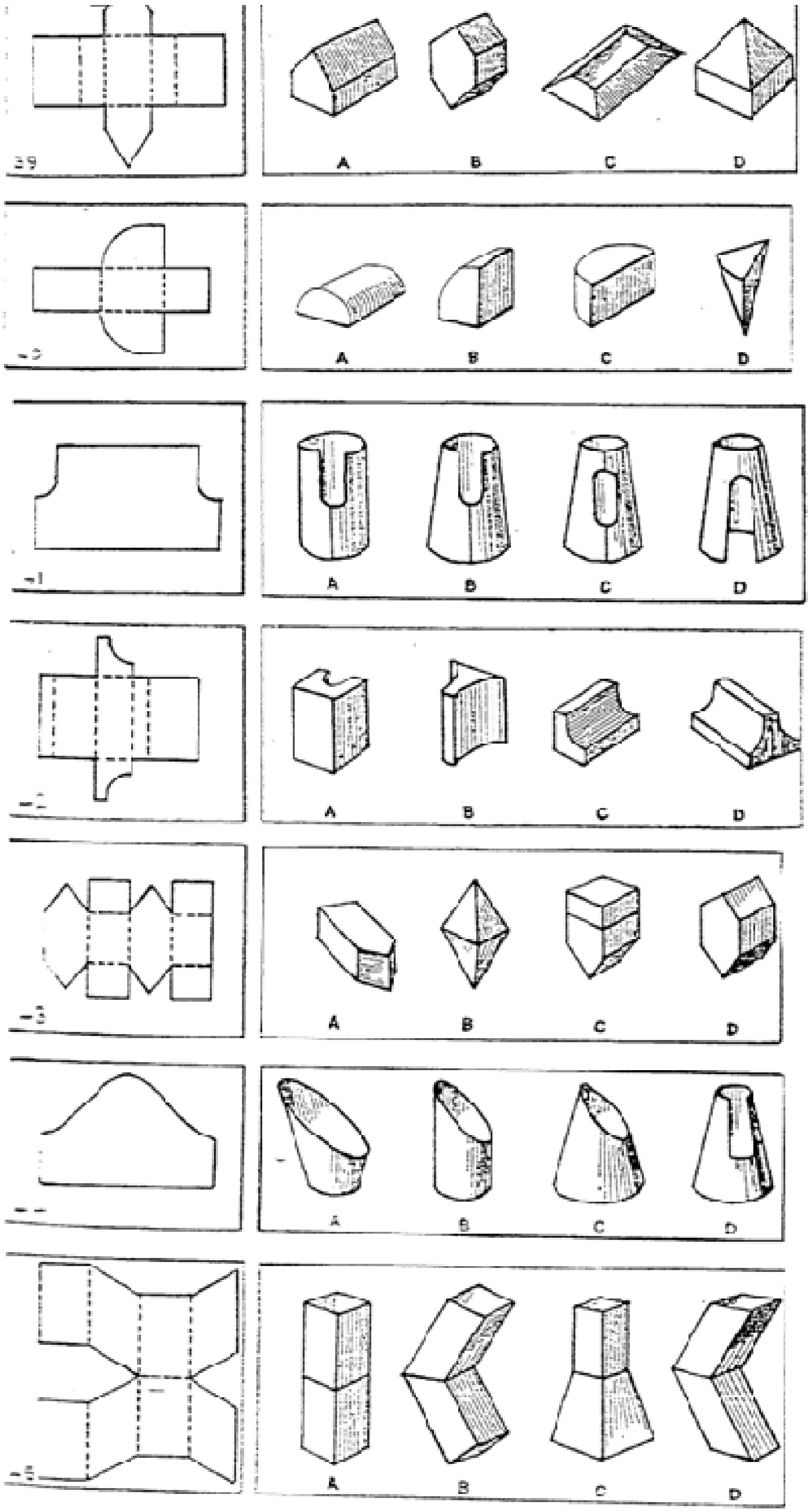
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