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Benefits of self-paced learning modules for teaching quantitative methods in environmental science

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This is a multiple-indicators evaluation of an innovative approach, using self-paced learning modules accompanying computerised exercises as an adjunct to teaching quantitative concepts and skills to environmental science students at university. The evaluation data, based on a pre-unit and a post-unit questionnaire survey completed by 38 students, show high levels of student satisfaction with the unit as a whole, and the self-paced workbooks in particular. Students also indicated a clear preference for learning from self-paced workbooks compared to learning from textbooks. Some students applied the quantitative skills acquired to other academic units, or took the initiative to learn to use additional statistical procedures (not covered in the unit) for academic purposes. However, comparison of students' levels of interest and confidence in quantitative subjects before and after the completion of the unit did not yield significant changes. Implications of the research findings for university science education are discussed.

Introduction

Outcome studies have indicated that self-paced educational delivery strategies are generally among the most effective educational innovations in higher education and could constitute an effective adjunct to, and in some cases largely replace, conventional classroom teaching (Bowles 1988, Kolner *et al.* 1986, Spencer 1991). Self-paced learning enables students to have control over the location, time and pace of their own learning, and this increased autonomy can possibly lead to improved motivation and cuts in staffing costs through the reduction of the amount of teacher-student contacts.

Self-paced educational delivery strategies are based on the Keller Plan (Keller 1968) or the Personalised System for Instruction (PSI), which spells out learning objectives for students and utilises operant learning principles. Students get immediate reinforcement for successful achievements and feedback to enhance their learning. They are required to master an easier module before progressing to a more advanced one and have access to tutorial assistance for additional feedback and support.

Research on learning outcomes of PSI has shown positive results in student performance. Kulik *et al.*'s (1979) meta-analysis of 75 outcome studies of college teaching utilising Keller's PSI shows that it generally produces superior student achievement. On average, PSI raises the final examination score of a typical student in a typical class from the 50th to 70th percentile. In another review article, Spencer (1991) noted that PSI was among one of the most potent pedagogic inno-

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vations as compared to traditional classroom teaching, giving an average effect size of 0·7. This means that the innovation increases the performance of a group of students exposed to PSI by an amount equal to 0·7 times the standard deviation unit of the control group.

Students' attitudes towards PSI, another outcome indicator, have also been shown to be favourable. Kulik *et al.*'s (1979) meta-analysis found that students using PSI generally rated the quality of their learning more highly than those taught by conventional classroom teaching.

More recent educational innovations including combining the use of the Keller Plan with electronic technology. Rae (1993) used videotapes, an interactive videodisc, and computer-delivered tutorials as part of a Keller Plan approach in the teaching of discrete mathematics and reported that in this way improved examination marks can still be obtained even when the amount of tutorial support is reduced to an economic level. Bowles's (1988) survey with a leading educationist from each of nine North American colleagues revealed the consensus view that computerised, self-paced learning could improve pedagogic standards and reduce teachers' routine management tasks. Specific advantages mentioned include improving student motivation, the ability to work without the direct observation of teachers, and the opportunity to attempt problems several times.

The numerous potential advantages of combining the self-paced approach with the use of computers have prompted the authors and other members in a teaching team at the University of Canberra (headed by the second author) to design and evaluate an innovative approach to teaching quantitative methods in environmental science. A National Teaching Development Grant awarded by the Committee for the Advancement of University Teaching in 1993 provided the necessary funding to produce four self-paced learning modules that would accompany computing exercises done either on or off campus for use as teaching materials in the unit.

This article reports the evaluation of the Quantitative Methods in Environmental Science unit that had incorporated the self-paced modules and was taught in Semester 1, 1993 at the University of Canberra. The four modules provide an opportunity for students to achieve the mastery of statistical application skills according to a graded sequence of difficulty. The unit's aim was to provide students with the opportunity to gain knowledge, understanding and sound practical skills in the application of analysis techniques of general use in field and experimental ecology. The unit was one semester long and designed for second year undergraduate students in the Faculty of Applied Science. In addition to the modules allowing self-paced learning, there were two hours of lectures per week and optional practical classes.

The content of the self-paced modules, in the form of workbooks, was on learning statistical analyses using the computer package SAS on IBM-compatible personal computers. The workbooks use real-life examples from Australian environmental sciences and contain summaries of key statistical concepts, syntax notes on SAS commands, and self-assessment questions. Site licensing agreements permitted students to install copies of the package on their home personal computers without charge. These arrangements enabled students to work through examples and assignments at their own pace using either personal computers available on campus or at home or both.

Five to seven two-hour practical classes were scheduled every week to provide opportunities for students to consult with staff regarding any problems they might have come across in completing the modules. Attendance at the practical classes was voluntary and students were welcome to attend as many classes per week as they wished.

Unit assessment was based on students' performance on their workbook exercises (50%) and a final examination (another 50%). Each workbook also included a non-assessable self-assessment exercise, comprising multiple-choice and short-answer questions.

The present study addresses whether, and in what ways, students benefited from the use of the self-paced learning method. One approach is to survey student satisfaction with various aspects of the unit, especially those associated with the self-paced workbooks. It is also useful to ask students to compare learning from the workbooks with learning from the more traditional teaching methods in the unit, such as studying the textbook or learning from lectures.

Outcome measures of the effectiveness of the unit, such as transfer of learning, also need to be considered. Successful outcomes are indicated by students extending the skills acquired in the unit (in this case SAS data analysis skills) to:

- trying out SAS procedures other than those taught in the unit,
- studying other units, and
- attempting other computerised statistical packages.

Another indication of the effectiveness of the unit is the adoption of a more positive attitude towards related subjects. In this case, this may be demonstrated by higher levels of interest and confidence in statistics and use of computer packages.

In the present study, all these various indicators of effective learning were examined. Agreement among the multiple indicators will lend greater credibility to the results obtained. As the usefulness of any computer-based learning depends partly on student access to the appropriate computing facilities, the present survey also included a number of questions on student access to computing resources.

Method

Subjects and procedure

Pre-unit questionnaires were distributed to the 80 students who attended the unit's first lecture in March 1993. While the participation in the survey was voluntary and anonymous, participants were requested to put down their student identification number or to devise their own confidential code to enable future matching with post-unit questionnaires. Of the 78 questionnaires returned, only 72 had codes written on them. The post-unit questionnaires were mailed out to the students in September 1993, three months after the completion of the unit. Of the 37 students who returned the post-unit questionnaires in pre-paid envelopes addressed to the independent investigator, only 35 could be matched with a pre-unit questionnaire. Reminders were sent out to the students in March 1994, when they had returned to resume their university studies. This resulted in another three matched sets of questionnaires.

The final sample was 38 students who completed both pre- and post-unit questionnaires. This represented 46·9% of a total of 81 students who were enrolled in the unit. Eighteen of the respondents were male, 19 were female, and one was unspecified. The actual numbers of students enrolled in the unit were 52 males and 29 females. It follows that 34·6% of male students and 65·5% of female students responded to both surveys, showing a much higher female participation rate.

The distribution of the respondents' self-reported grades in the unit is listed in Table 1, alongside that of the entire class. It appears that the final sample contained a lower proportion than the whole class of students who had obtained the lower grades of Pass and Fail.

Measures

The pre-unit questionnaire surveyed students' demographic and academic background, their access to a home personal computer and funds for purchasing textbooks, and their interest and confidence in statistics, mathematics and computer packages. Five-point Likert-type scales were used. Students were also invited to write down their expectations about the unit and any comments regarding their course related to statistics and mathematics.

The post-unit questionnaire was in eight parts

- Part A had Likert-type attitudinal scales on student' satisfaction with the unit as a whole, with half of the items worded negatively to minimise response sets. The positive and negative statements were placed randomly to avoid bias in any one direction.
- Part B surveyed student satisfaction with the self-paced learning modules, again using Likert-type scales, half of which were negatively worded items.
- Part C examined student satisfaction with learning based on the textbook as compared to learning using the self-paced modules.
- Part D was similar to Part C, but compared learning from lectures to learning from self-paced modules.
- Part E contained questions on access to personal computers.

Table 1. Distribution of grades awarded in Quantitative Methods in Environmental Science, Semester 1, 1993.

	Number of students[a]	
Grade	*Present sample*	*Entire class*[b]
High distinction	3 (7·9)	3 (3·7)
Distinction	5 (13·2)	7 (8·6)
Credit	16 (42·1)	26 (32·1)
Pass	9 (23·7)	27 (33·3)
Fail	3 (7·9)	18 (22·2)
Withdrawn	1 (2·6)	0 (0·0)
Unspecified	1 (2·6)	0 (0·0)
Total	38	81

[a] Percentages are shown in brackets.
[b] Based on the unit's final assessment return.

- Part F enquired about transfer of learning from the unit.
- Part G was on post-unit interest and confidence in statistics, mathematics, and computer packages.
- Part H: respondents were invited to write down any other comments on the unit.

All the items assessing attitudes in the post-unit questionnaire were in the form of five-point Likert-type scales.

Prior to data analysis, some items in Parts A and B of the post-unit questionnaire were reverse scored so that higher scores consistently indicate greater levels of satisfaction with the unit or the self-paced modules.

Results

Students' background from pre-unit questionnaires

The 38 respondents' age ranged from 18 to 34 years, with a median of 21·5 years, and a mode of 19 years. Thirty-three respondents (87%) were full-time students. Twenty-seven (71%) of the subjects did this as a compulsory unit, four (11%) did it upon recommendation, and seven (18%) did it as an elective of their choice. Three respondents (8%) were repeating the unit.

Of the 38 students, 18 did their major in Vegetation and Wildlife, eight in Soil Science, six in Parks and Recreation, five in Water Science, two in Geology, and five in other specialisations in Applied Science. Thirty-two of the sample reported pursuing a single major.

In terms of the students' academic background, 33 (87%) had completed a mathematics unit, 35 (92%) had completed a statistics unit, and only two (5%) had completed a computing unit prior to their enrolment in Quantitative Methods of Ecology.

Prior to doing the unit, 18 (47%) students said they had basic working familiarity with keyboard skills, and seven (18%) could touch-type. However, eight (21%) students described their keyboard skills as rudimentary, and five others (13%) said they were non-existent.

In another pre-unit question on skills with personal computers, 15 (40%) described themselves as having basic working familiarity, and four (11%) claimed competence. Eleven respondents (29%) felt they had only rudimentary skills, and eight (21%) said they were non-existent.

Regarding prior knowledge of the MS-DOS operating system, only three (8%) claimed basic working familiarity, and another three (8%) claimed competence. Nineteen (50%) described their knowledge of MS-DOS as non-existent, and 13 (34%) said they had only rudimentary knowledge.

In the pre-unit questionnaire, 15 (39%) said they had an IBM-compatible personal computer at home. Twenty-two (58%) said they did not have a home PC, and would not consider purchasing one.

The pre-unit survey revealed three recurrent student expectations of the unit: improving understanding of statistics, gaining computing skills, and enhancing employability through improved statistics and computing skills.

Evaluation of unit as a whole

Table 2 presents a summary of the student evaluation of the unit as a whole as indicated on the post-unit questionnaires. The unit was generally perceived as interesting, providing adequate opportunities for consultation, improving understanding of statistical theory, improving ability to choose appropriate methods of data analysis, teaching sound practical skills using SAS, enhancing ability to interpret statistical results in the context of the problem at hand, well-integrated, and overall providing a valuable learning experience.

Fifteen (40%) agreed or strongly agreed that this was one of the better units they had done, while an equal number were not certain about this; eight others (21%) disagreed or strongly disagreed that this was one of the better units.

There were two other items attracting negative evaluations from more than 20% of the respondents. Ten (26%) rated opportunities to consult academic staff as inadequate. Eight (21%) felt various parts of the unit (lectures, practicals, workbooks and readings) did not integrate well.

Table 2. Evaluation of the unit as a whole.

Item	*Percentage of respondents (N=38)*				
	Very unfavourable	*Unfavourable*	*Not certain*	*Favourable*	*Very favourable*
The unit was interesting	0.0	13·2	13·2	62·2	10·5
Opportunities to consult academic staff were inadequate	10·5	15·8	18·4	52·6	2·6
Improved my understanding of statistical theory	0·0	5·3	2·6	63·2	28·9
Did not improve my ability to choose methods of data analysis appropriate to the problem at hand	0·0	23·7	10·5	57·9	7·9
Taught me sound practical skills using SAS	0·0	7·9	23·7	50·0	18·4
Did not enhance my ability to interpret statistical results in the context of the problem at hand	2.6	15·8	7·9	55·3	15·8
Various parts of the unit (lectures, practical, workbooks, readings) did not integrate well	0·0	21·1	15·8	57·9	5·3
Overall a valuable learning experience	0·0	5·3	10·5	65·8	18·4
This is one of the better units I have done	7·9	13·2	39·5	31·6	7·9

Self-paced learning modules

Table 3 summarises student evaluation of the self-paced learning modules in the form of the workbooks. The workbooks were typically seen as interesting, adequately organised, having easy-to-follow instructions, having a satisfactory style of presentation, using adequate Australian examples, relevant to environmental sciences, enhancing understanding of key statistical concepts, containing useful worked examples, syntax notes on SAS commands and summaries of key statistical concepts, enabling students to learn at their own pace, presenting problems in a graded sequence of difficulty, valuable in developing competence in SAS, and containing useful self-assessment questions for feedback purposes. The majority of students also agreed that they had received adequate help from staff regarding problems with the use of the workbooks and that they would welcome similar self-paced workbooks in other units.

Three out of 18 items in this section attracted unfavourable evaluation from more than 20% of the respondents. Fourteen (37%) thought there was insufficient guidance given in the workbooks on where to find information in the textbook. Eleven (29%) felt that the workbooks did not provide adequate feedback along the way. Eight (21%) students thought they had not received adequate help from staff regarding problems arising from the use of the workbooks.

Student opinions on the workload associated with the completion of the workbooks and their level of difficulty were also sought. Twenty (53%) thought the workload was about right, while 17 (45%) found it was too much. As for the level of difficulty of the workbooks, 32 (84%) felt it was about right, and five (13%) said it was too difficult.

Optional practical classes were scheduled as an integral part of self-paced learning. The need for students to attend practical classes in part indicates the insufficiency of the workbooks for independent learning purposes. In this survey, two students (5%) felt that they did not need to attend any of the practical classes. Six (16%) said they needed to attend some but not all of the classes. Fifteen (40%) said they attended one class per week. On the other hand, eight (21%) sometimes needed to attend more than one class per week, whereas seven (18%) routinely attended more than one class per week.

Students were asked whether their expectations from completing the workbooks corresponded to the actual grades obtained. The responses could indicate some measure of whether students had obtained adequate feedback from completing the workbooks. Twenty-five (66%) felt that their expectations had corresponded to the final grades; nine (24%) felt there had been a discrepancy.

Overall, 12 (32%) students found the workbooks to be a very valuable learning experience, 17 (45%) found them quite valuable, and eight (21%) found them of some value. Only one person (3%) felt they were not valuable. This positive overall evaluation is consistent with the satisfaction that students have generally expressed towards various aspects of the self-paced learning modules.

Comparison between learning from textbooks and from workbooks

Two textbooks had been recommended to the students. Ten (26%) found the first book to be the most useful, and eight (21%) rated the second book the most useful. Twenty respondents (53%) said they did not generally refer to a textbook.

Table 3. Evaluation of the results of the self-paced learning modules.

Item	*Pecentage of respondents (N=38)*				
	Very unfavourable	*Unfavourable*	*Not certain*	*Favourable*	*Very favourable*
The workbooks were interesting	2·6	7·9	10·5	63·2	15·8
Organisation of their content was inadequate	0·0	13·2	13·2	57·9	15·8
Instructions were hard to follow	0·0	10·5	5·3	71·1	13·2
There was insufficient guidance given in the workbooks on where to find information, or what to look for, in the textbook	10·5	26·3	23·7	36·8	2·6
Style of presentation was satisfactory	2.6	2·6	13·2	65·8	15·8
There was adequate use of examples with an Australian context	0·0	2·6	2·6	50·0	44·7
Content was irrelevant to environmental sciences	0·0	0·0	5·3	50·0	44·7
Concrete examples enhanced understanding of key statistical concepts	0·0	2·6	13·2	55·3	28·9
Worked examples were useful	0·0	0·0	2·6	42·1	55·3
The syntax notes were useful	7·9	7·9	10·5	44·7	28·9
Summaries of key statistical concepts were not useful	0·0	0·0	21·1	52·6	26·3
Did not provide adequate feedback along the way	5·3	23·7	26·3	39·5	5·3
Enabled me to learn at my own pace	7·9	7·9	10·5	63·2	10·5
Problems were presented in a graded sequence from less to greater difficulty	2·6	13·2	21·1	50·0	13·2
The workbooks were of little value in developing my competence in SAS	0·0	0·0	10·5	57·9	31·6
I did not receive adequate help from staff regarding problems with the use of the workbooks	7·9	13·2	10·5	44·7	23·7
I found the self-assessment questions ('Q' Package) provided useful feedback on my performance in the unit	5·3	13·2	18·4	50·0	13·2
I would not welcome similar self-paced workbooks in other units	2·6	2·6	10·5	55·3	28·9

It may be speculated from the low rate of student utilisation of textbooks that students perceived the workbooks to be more useful than the textbooks in meeting assessment requirements and it would be pragmatic to focus on the former. Table 4 provides a summary of student satisfaction with the textbooks relative to that of the workbooks. Students generally preferred the workbooks with regard to understanding key concepts and theory, improving their ability to choose appropriate methods of data analysis, acquiring statistical analytical skills using SAS, and enhancing their ability to interpret statistical results in the context of the problem at hand.

Comparison between learning from lectures and from workbooks

Table 5 summarises student satisfaction with learning from the lectures relative to learning from the workbooks. The responses suggest that lectures and workbooks were perceived to be about the same in improving students' understanding of concepts and theory, and their ability to choose appropriate methods of data analysis and to interpret statistical results in the context of the research question. However, students generally preferred the workbooks to lectures in acquiring statistical analysis skills using SAS.

Access to personal computers

The effectiveness of any computer-assisted learning inevitably depends on student access to the computers. In this unit, site licensing agreements enabled students to access the SAS package in various computer laboratories on campus as well as on their own personal computers at home, thus improving student access to the self-paced learning activities.

Table 4. Comparison between learning from textbooks and from workbooks.

Item	*Percentage of respondents (N=38)*				
	Textbooks much more satisfactory	*Textbooks more satisfactory*	*About the same*	*Workbooks more satisfactory*	*Workbooks much more satisfactory*
Understanding key concepts and theory	0·0	20·6	8·8	38·2	32·4
Choosing appropriate methods of data analysis	0·0	2·9	17·6	44·1	35·3
SAS statistical analysis skills	0·0	2·9	0·0	35·3	61·8
Interpreting statistical results	0·0	5·9	11·8	47·1	35·3

Table 5. Comparison between learning from lectures and from workbooks.

Item	*Percentage of respondents (N=38)*				
	Lectures much more satisfactory	*Lectures more satisfactory*	*About the same*	*Workbooks more satisfactory*	*Workbooks much more satisfactory*
Understanding key concepts and theory	7·9	15·8	36·8	31·6	7·9
Choosing appropriate methods of data analysis	2·6	13·2	44·7	36·8	2·6
SAS statistical analysis skills	0·0	10·5	21·1	52·6	15·8
Interpreting statistical results	5·3	26·3	34·2	28·9	5·3

The current survey shows that 31 students (82%) used only the university's computer laboratories. One person (3%) used only a home computer, and six students (16%) said they used both university and home computers.

Thirty-one (82%) respondents used university computers to complete their SAS exercises all the time. Two (5%) used university computers 90% of the time. One person (3%) used university computers 30% of the time. Three respondents (8%) used university computers 10 to 20% of the time. Only one individual (3%) used a home computer all the time.

With regard to student satisfaction with their access to university computers for completing their exercises, four (11%) rated the access as very satisfactory, and 25 (66%) found it quite satisfactory. Three (8%) regarded the access as neither satisfactory nor unsatisfactory. Six (16%) thought it was quite unsatisfactory.

Having a personal computer with an adequate configuration at home (an XT machine or more sophisticated, with a hard disk of at least 20Mb) would have addressed any concern about access. In this study, 12 students (32%) had a home computer, but only seven of them had used it for completing exercises for the unit. This included one respondent (3%) who had purchased a computer partly to be able to complete the exercises at home.

Transfer of learning from the unit

In a set of questions regarding transfer of learning from this unit, indications of the effectiveness of the unit in enhancing students' general ability and willingness in applying statistical analysis skills were sought.

Students were asked whether, during and after their completion of the unit, they had used SAS procedures other than those required in the unit. Twelve (32%) said they had tried between one and three other SAS procedures; one student (3%) had used four or more different procedures.

In another question, students were asked to indicate how important was knowledge of SAS to their ability to achieve good results in the more advanced units Ecology and/or Community Ecology. Seven (18%) felt their knowledge of SAS was essential to achieving good results. Eleven (29%) said it was very useful, and eight (21%) rated it to be of some value. Five (11%) thought it was of no value at all, but it should be noted that one of these students had not yet done the unit on ecology, and another one had completed ecology prior to completing Quantitative Methods in Environmental Science.

Students were also surveyed regarding their continued use of SAS for data analysis. Twenty-six (68%) had not used it since the completion of the unit. Two (5%) continued to use SAS at a frequency of about once a month or more; ten others (26%) also used it, at a frequency of less than once a month. Students who gave a positive answer were asked to specify the purposes for which they had used SAS. Their responses show that they used SAS for other academic units—Community Ecology, Catchment Hydrology, Ecology, Environmental Classification and Ordination, and Research Project in Applied Science.

Some students may also have demonstrated their transfer of learning from the unit by attempting other computerised statistical packages as well as SAS. Five (13%) attempted to use other computer packages, including Minitab, Statview, PATN and Excel.

Attitudes towards quantitative subjects

Students were surveyed regarding their interest and confidence in statistics, mathematics and use of computer packages in both the pre-unit and post-unit questionnaires. Wilcoxon matched-pairs signed-ranks tests were performed to examine whether students' attitudes towards these quantitative subjects had changed on completing the unit. In view of the multiple testing, the Bonferroni family-wise correction to the probability levels was applied. The results obtained show no significant changes in student interest and confidence in statistics, mathematics and use of computer packages at a probability level of 0·05.

Post-unit modal responses of these five-point attitudinal items, similar to those for the pre-unit questionnaire, tend to be around the mid-point and may be described as reflecting a 'lukewarm' attitude. Seventeen (45%) said on the post-unit questionnaires they were quite interested in statistics, whereas 14 (37%) were only a bit interested. As regards interest in mathematics, eight (21%) were quite interested and 18 (47%) were a bit interested, but ten (26%) were not interested at all. For interest in using computer packages, 19 (50%) were quite interested, and nine (24%) were a bit interested.

For the post-unit questions on confidence, 19 (50%) said they were quite confident, while 16 (42%) expressed little confidence in statistics. Again 19 (50%) reported they were quite confident in mathematics, and 12 (32%) said they had little confidence. Twenty-four (63%) were quite confident in using computer packages, while nine (24%) had little confidence.

Discussion

Multiple indicators of student satisfaction and transfer of learning were employed to assess the effectiveness of an innovative approach to teaching quantitative meth-

ods that incorporated the use of self-paced workbooks accompanying exercises on a statistics computer package. A pre-unit questionnaire was included to survey students' computing skills and attitudes towards quantitative units prior to the unit.

The results obtained from the pre-unit survey suggest that half of the respondents' computer literacy skills had been either rudimentary or non-existent. Moreover, the respondents had generally low levels of interest and confidence in statistics, mathematics and computer packages.

Despite this, student evaluation of the unit (obtained at three months or longer after the completion) showed that students were generally satisfied with various aspects of the unit as a whole. They were particularly satisfied with the numerous facets of the self-paced learning modules. However, it should be noted that the students completing the post-unit questionnaire generally had higher grades than those who did not. It is likely that the student evaluation results reported would have been less favourable had all the students responded in the evaluation.

Among the respondents, there is some evidence of student preference for the self-paced learning method over more traditional methods of learning. Most students in the unit expressed greater levels of satisfaction with learning from the self-paced workbooks than from the textbooks. Students generally found the lectures and self-paced workbooks to be equally satisfactory, except that the workbooks were more satisfactory in learning statistical analysis skills.

There are additional indications that many students transferred their learning from this unit to their other academic tasks. They took the initiative to use SAS procedures other than those required in the unit and continued to use SAS for data analysis in other academic units after completing Quantitative Methods in Environmental Science.

It should be noted that the success of any computer-assisted self-paced learning programs hinges on student access to computing facilities and consultation sessions. The students surveyed were mostly satisfied with both aspects, while some would welcome greater levels of access. While site licensing arrangements had made copies of SAS available to students' home personal computers free of charge and some had taken advantage of this, some of these students had preferred to use university computing facilities most of the time. Still, the licensing arrangements had made it possible for some students to complete most of their exercises at home. This should certainly be welcomed by students studying part-time or those with family commitments.

While student evaluations of the unit were generally favourable, the results indicate that the following areas have room for improvement. A number of students had reservations about the adequacy of their opportunities to consult academic staff, thought various parts of the unit did not integrate well, felt that there was insufficient guidance given in the workbooks on where to find information in the textbook, were uncertain about the adequacy of feedback after completing the workbooks, and found there was too much work involved in completing them.

An interesting question relates to whether or not the present self-paced learning modules make learners more self-sufficient in the learning process, compared to the more traditional methods of having to attend lectures and practicals. Present results show that the majority of students needed to attend consultation sessions in the form of practical classes every week. This suggests that users of these self-paced modules cannot be expected to be entirely self-sufficient. Results have shown no clear preference for workbooks over lectures in student learning of the

theoretical aspects of statistical applications. However, students clearly preferred the workbooks in acquiring actual statistical analysis skills. This may be because of the active learning strategy employed in completing the workbook exercises. Learners found themselves in a hands-on interactive situation in front of a monitor and had prompt feedback from the computer.

Although the use of self-paced workbooks has not apparently discouraged students from attending classes, present results indicate that some students may have focused all their attention on the workbooks to the exclusion of other sources of reading. The low utilisation of the textbooks as compared to the workbooks by many students is an area of concern. It is arguable that because 50% of the unit assessment was on completing the workbook exercises, many students may have chosen to follow closely only the workbooks in the light of competing needs for their time in other units. In any case, many students rated the work load associated with the workbooks alone to be excessive. While the focus on the workbooks may demonstrate the superiority of the hands-on and self-paced approach and serve pragmatic purposes such as meeting assessment requirements, students could have missed out on the more subtle and detailed discussions of theory, applications and issues that texts and reference books can offer.

It was initially expected that an effective statistical applications unit could induce higher levels of interest and confidence in statistics and the use of computer packages, but not necessarily in mathematics. However, there was no support for this in the findings. Post-unit levels of interest and confidence in the quantitative subjects were mostly moderate to low. Comparison of pre-unit and post-unit attitudes has shown no significant changes in student interest and confidence in statistics, mathematics and use of computer packages. This is despite a generally favourable evaluation of the unit and various students' abilities to transfer their learning in this unit to other academic tasks. Interestingly, even those students awarded a high distinction in the unit did not consistently report increase in interest and confidence in quantitative subjects.

A plausible reason for a lack of increased confidence is that a semester's exposure to statistical theory and procedures could have impressed on the students the complexity and sophistication of this subject. On completion of the unit, students might begin to realise there were many other aspects of mathematics and statistical applications that they did not fully understand. Also, it may be possible that many students perceive statistical packages as useful tools and statistical applications as chores, often only a means to an end. Clearly many of the students surveyed were not particularly enthusiastic about the applications of these tools and it is conceivable that some may have viewed them as a necessary evil. Indeed, a student commented on the unit in those terms in the pre-unit survey.

A limitation of the present study is that the sample obtained consisted only of half of the students enrolled in the unit. It was under-represented by male students and by students awarded lower grades. If it could be assumed that students with less satisfactory grades would tend to give less favourable evaluation of the unit and the workbooks, then the present results are likely to have painted a more positive picture than if the entire class had responded to the evaluation survey. Nevertheless, 'within subjects' evaluation has quite clearly established student preference for learning from the self-paced workbooks rather than learning from textbooks. Students also preferred workbooks to the more traditional lecture method in learning computerised statistical analysis skills.

Conclusions

This study has found multiple indications of the benefits of using self-paced workbooks in learning quantitative methods in environmental science. However, two access conditions have been identified for effective student use of the workbooks. First, satisfactory completion of the self-paced modules depends on having access to guidance from staff when needed. It is unrealistic to expect that the adoption of self-paced modules would necessarily achieve savings through the reduction of formal contact hours. Second, just as in any other quantitative methods unit, ample access to university computers is required. In the present study, even students with sophisticated home computers tended to prefer to complete their exercises on campus where there was access to staff support. The benefits of the self-paced modules in learning statistical theory and techniques appear to be best realised when they are used in a supportive environment and in conjunction with formal class contact.

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