Int. J. Engng Ed. Vol. 19, No. 4, pp. 525–531, 2003
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Effects of Instructional Intervention Strategies on Students at Risk in Engineering Education*

GRACE LIM, KHENG SWEE CHUA and KHEE YUN WEE
Temasek Polytechnic, 21 Tampines Ave 1, Singapore 529757. E-mail: kehbuoy@tp.edu.sg

The study was conducted on repeat students ($N = 139$) from the second year Diploma in Mechatronics taking the Mechatronics Science 2 subject. Various forms of instructional support were provided. The students completed a pre-test and post-test self-report questionnaire to assess changes in their motivation and beliefs towards learning of the subject. A follow-up interview of students was conducted. Analyses of student responses indicated that the instructional intervention strategies did bring about significant changes in self-efficacy and intrinsic motivation among the students, perceived gain in knowledge and skills of the subject and positive correlations among various aspects of motivation. Implications for teaching are discussed.

INTRODUCTION

CONTEMPORARY MOTIVATION research in academic settings indicates that a student's self-efficacy is positively related to achievement and motivation [1–5]. The greater the self-efficacy, the greater the persistence, perseverance and effort is extended to learning situations, which lead to improved achievement [2–4, 6–7].

Bandura [8] defined self-efficacy as 'the conviction that one can successfully execute the behaviour required to produce the outcomes' (p. 79). Self-efficacy thus conveys one's perceived capabilities or judgements in performing specific tasks. People who have a high sense of self-efficacy tend to work harder and persist longer in difficult situations.

Learning engineering is tough for many students, particularly more so for students at risk, as it requires persistence and effort. The aim of this study was therefore to investigate the effects of introducing a repertoire of instructional intervention strategies on repeat students with respect to changes in their motivation and beliefs towards the subject under study.

Prior to the study, a team of staff from Promoting Good Teaching Practice at the Temasek Engineering School had identified attributes of students at risk along with barriers to learning, and factors interfering with teaching and learning among these students in the school. Subsequently, a framework for enhancing student motivation and learning attitude was formulated with the aim of helping these students by enhancing their self-efficacy and self-regulation (Lim *et al.* [9]). The framework comprised four aspects: lecturer-focus, student-focus, assessment, and school-wide support. This study constituted a pilot-run of the framework.

It was hoped that insights, experience and knowledge gained from the study could be shared with other engineering faculty staff in helping students at risk cope better with their learning who could otherwise have dropped out from their courses.

OBJECTIVES OF THE STUDY

The study sought to address the following questions:

1. How would the deployment of instructional intervention strategies affect the students' beliefs and motivation towards the subject they were learning?
2. Would there be any perceived gain in knowledge and skills of the subject after the completion of the study?
3. Would there be any correlations among the motivation variables in the study?
4. How would the findings implicate teaching in engineering education?

METHOD

Sample

The participants in this study were 139 repeat students from the second year Diploma in Mechatronics taking the Mechatronics Science 2 (MTNSc2) subject in the academic year of 2000/2001. The majority of these students repeated their Year 1 previously and now progressed to Year 2 to take MTNSc2 subject for the first time. A small number of these students (7 out of 139), however, were Year 2 repeat students who re-took the

* Accepted 10 December 2002.

MTNSc2 subject. This latter group of students had therefore undergone both the traditional method of teaching in the previous semester and the intervention method in this study.

Mechatronics Science 2 (MTNSc2) subject

The essentials of Mechatronics Science 2 are in the area of *Dynamics*, namely *Kinematics*, *Kinetics*, *Work & Energy/Momentum*. These three basic topics form about 60% of the Semestral Examination content. It is noted that if students taking this subject are weak in the *Dynamics* content area, they will not do well in the examination

The subject has been traditionally taught in lecture mode, complemented by tutorials and lab sessions. Students listen and take notes passively in the lectures, solve dynamics-related exercises in tutorials, and conduct topical experiments in lab sessions. With this mode of instruction, students have been found to have difficulties in grasping and understanding *Dynamics* concepts and subsequently lost their interest in the subject. Consequently, these students normally did not do well in the subject and some of them failed it and were required to re-take it. The inherent difficulties in teaching and learning of *Dynamics* have been cited elsewhere [10].

Deployment of instructional intervention strategies

To enhance teaching and learning in his *Dynamics* classes, the second author decided to implement some of the guidelines as suggested in the motivation framework [9]. The fundamentals of the subject were still taught via lectures and tutorials. However, the approach to teaching and learning in the lab sessions was modified from having topical experiments to the one, which was integrated. It was during the lab sessions that the following instructional intervention strategies were deployed:

- Incorporating **subject relevance** by introducing a real-life mechanical design case study named *Dynamics Project*.
- Establishing **connections among topics** in dynamics leading to acquisition of a system perspective instead of topical learning.
- Recalling and applying **prior knowledge** on engineering drawing in solving the design problem.
- Introducing **teacher model** and **peer model** in solving the design problem.
- Formulating a **learning contract** among the student groups.
- Fostering **team work and support**.
- Providing **feedback** on student progress.
- Providing **reward** in terms of grading (an additional 10% allocated for the work done in *Dynamics Project*).
- Using a computer **modelling and simulation** tool.
- Assigning **written assignment**.

INSTRUMENTS

Self-report questionnaire

A 12-item pre-test and post-test questionnaire was adapted from Nicols and Utesch [3] to assess various aspects of student motivation and beliefs towards learning. A sample of the questionnaire is presented below:

- I do the work in the *Dynamics Project* because I like learning interesting things.
- I work hard in the *Dynamics Project* so I can get a better grade.
- I find the *Dynamics Project* challenging.

The items, categorised into six variables, were randomly ordered. The six variables were learning goals (LG), intrinsic motivation (IM), extrinsic motivation (EM), self-efficacy (SE), persistence (PE), and self-regulation (SR). Both the pre-test and post-test questionnaire contained the same twelve close-ended questions except that, there was one open-ended question in the post-test questionnaire, which investigated the perceived gain in knowledge and skills in the subject among the participating students.

Lab observation

Observations were conducted on the teaching and learning processes, the students' learning behaviour and responses and team activities in discussions and in performing computer simulations.

Follow-up interview

Follow-up interviews were conducted on the instructor and on randomly selected students from the sampled classes as well as students who re-took the subject. The interviews with the students served to enhance retrospective recall of their experiences in the *Dynamics Project* and their overall experience in the MTNSc2 subject. The interviews were informal but structured with a 10-item questionnaire and one free-form feedback. A sample of the questionnaire is presented below:

- How do you feel about the *Dynamics Project*?
- You did the *Dynamics Project* because you found it interesting and relevant or because you could obtain a better grade in MTNSc2 subject or both?
- Did you find that the *Dynamics Project* help you to understand and learn MTNSc2 subject better? Why or why not?
- After you had completed the *Dynamics Project*, what was your level of confidence in dynamics topics—High, Medium, Low?
- With the knowledge and skills acquired from the *Dynamics Project*, do you believe that you can solve similar mechanical design problems?

Procedure

On both pre-test and post-test self-report questionnaires, the students were requested to rate each item on a 5-point Likert scale, displaying ‘strongly agree’ with a score of 5 and ‘strongly disagree’ with a score of 1. The pre-test questionnaire was administered before the *Dynamics Project* commenced and the post-test after the completion of the project. The duration of the study lasted about 12–13 weeks.

RESULTS

Reliability analysis

The 12 items in the questionnaire were analysed with Cronbach’s alpha scale to establish reliability coefficient, which was 0.89 for both pre-test and post-test. The analysis indicates a high internal consistency for the motivational variables, namely learning goals (LG), intrinsic motivation (IM), extrinsic motivation (EM), self-efficacy (SE), persistence (PE), and self-regulation (SR).

Data analysis

Table 1 provides the descriptive statistics for each dependent variable. There were 6 motivational variables in this study. Each of them made up of 2-question items in the 12-item questionnaire, which were then arranged alternately to cancel out bias. Each of these has a point-scale of 1 to 5. The total of the paired question items were taken, so the maximum score for each variable is 10.

As students’ response to pre-test and post-test questionnaire was based on voluntarily basis, the number of students turned out for the post-test questionnaire was less than that of the pre-test session. This could be due to the heavier commitment in their study towards the end of the semester.

Figure 1 provides the changes in pre-test and post-test mean of the variables. The changes of mean for IM and SE are 0.44 and 0.43 respectively.

An independent t-test was performed on the variables for pre test and post-test to determine any significant changes in the students’ beliefs and attitudes. A positive change was anticipated. One-tail test was applied to assess any significant changes in the variables. The test was based on 95% confidence level, i.e. level of significance is 0.05. The hypothesis statement was:

$$H_0\colon\ \mu_a = \mu_b$$
$$H_1\colon\ \mu_a > \mu_b$$

Level of significance:

$$\alpha = 0.05$$

An independent samples test for each variable was conducted based on the assumption of equal variances. The t-test shows that the project has significant changes only in IM (intrinsic motivation) and SE (self-efficacy) and the changes in other variables are not significant. Significance for IM and SE are respectively 0.03 and 0.026 against 0.05.

For questionnaire item 13, a pair-t test was used to assess any perceived gain in knowledge and skills of the subject matter after the students had completed the *Dynamics Project*. One-tail test was used to assess any significant changes. The test was based on 95% confidence level, i.e. level of significance was 0.05. Table 2 provides the descriptive statistics of samples before and after the *Dynamics Project*.

The hypothesis statement was:

$$H_0\colon\ \mu_a - \mu_b = 0$$
$$H_1\colon\ \mu_a - \mu_b > 0$$

Level of significance:

$$\alpha = 0.05$$

The finding shows that the change of perceived gain in knowledge and skills of the subject after the project is significant (significance is 0 against 0.05). There is an increase of 33.28 in overall mean.

To determine the relative importance of the variables which contributes to the perceived gain, dominance analysis was performed based on the post-test results. Table 3 provides a summary of the dominance analysis which indicates learning goal as the predominant variable (55.79%),

Table 1. Descriptive statistics for each variable

	PROJ	N	Mean	Std. deviation	Std. error mean
LG	B	138	6.04	1.75	.15
	A	118	6.30	1.43	.13
IM	B	139	6.17	1.65	.14
	A	118	6.61	1.59	.15
EM	B	139	6.67	1.49	.13
	A	118	6.74	1.60	.15
SE	B	139	6.80	1.54	.13
	A	118	7.23	1.52	.14
PE	B	139	7.03	1.78	.15
	A	118	6.92	1.60	.15
SR	B	139	6.58	1.69	.14
	A	118	6.56	1.59	.15

B = Pre-test; A = Post-test.

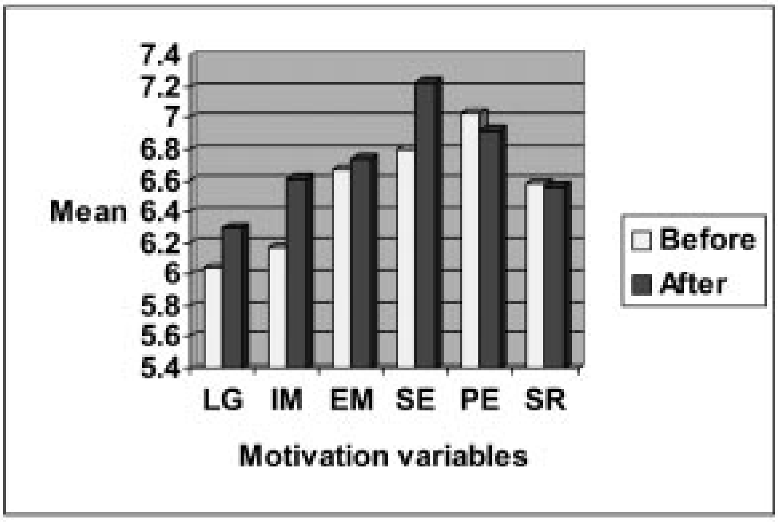

Fig. 1. Comparison of pre-test and post-test mean of the variables.

followed by intrinsic motivation as the second predominant variable (27.02%).

A correlation matrix of the six motivation variables was conducted for both pre-test and post-test respectively.

It was found that the correlation among the variables is positive. This indicates that an increase in one variable will potentially influence another. There are significant correlations between learning goals and self-efficacy (0.55, 0.59), learning goal and intrinsic motivation (0.75, 0.74), learning goal and extrinsic motivation (0.59, 0.56), intrinsic motivation and self-efficacy (0.56, 0.62), extrinsic motivation and self-efficacy (0.60, 0.61), persistence and self-efficacy (0.59, 0.53), extrinsic motivation and persistence (0.51, 0.66), self-regulation and persistence (0.66, 0.61). However, there is a relatively weaker correlation between self-regulation and learning goal (0.48, 0.41), self-efficacy (0.47, 0.41), extrinsic motivation (0.48, 0.38) and intrinsic motivation (0.39, 0.35) respectively.

Lab observation

The atmosphere at the lab sessions was generally relaxed and non-threatening, with the students being attentive and captivated by the teacher model and peer model in demonstrating various tasks in solving the problem posed. Good teamwork was observed among students in discussions and in conducting the computer modelling and simulation.

Table 2. Descriptive statistics of paired samples before and after the *Dynamics Project*

		Mean	N	Std. deviation	Std. error mean
Pair 1	BPROJECT	30.03	116	18.09	1.68
	APROJECT	63.31	116	15.57	1.45

Interview with the instructor

The instructor indicated that in comparing with past students under traditional dynamics teaching, these groups of students generally expressed a stronger interest in the subject, particularly in the *Dynamics Project*. This was partly evident in a greater enthusiasm and participation in the lab sessions with more questions posed by the students and partly by more out-of-class discussions by the student groups with the instructor.

Interview with students

The students indicated that initially they did the *Dynamics Project* as part of the requirement in the lab work but subsequently developed their interest in it when they were able to relate the learning with real-world experience. The students attributed their difficulties in learning engineering subjects to the lack of relevance and meaning in the subjects. Once they could see the relevance of their learning in the *Dynamics Project*, they began to enjoy it and were able to understand the subject better such as resolving forces, applying calculation formulae, and considering mechanical design constraints and assumptions more confidently. They were able to connect the learning among dynamics topics and other topics in MTNSc2 subject more effectively.

Both groups of students who re-took the subject and those who took it for the first time expressed that although the *Dynamics Project* did consume a fair amount of time for out-of-class group activities compared to traditional topical experiments, the effort and time were well spent because the project indeed made them think through it and relate better the concepts of the topics to real-life experience. They eventually discovered their own meaningful learning of dynamics so much so that when the time came for the final examination, they could revise the subject with ease and confidence.

The periodical review and feedback on their progress provided by the instructor were highly

Table 3. A summary of dominance analysis relative importance metrics

K	ALG (X1)	AIM (X2)	AEM (X3)	ASE (X4)	APE (X5)	ASR (X6)
0	0.187	0.131	0.041	0.045	0.016	0.039
1	0.1358	0.0802	0.0112	0.0136	0.003	0.0124
2	0.1117	0.0567	0.0053	0.0061	0.008	0.0096
3	0.0923	0.0387	0.0024	0.0026	0.0113	0.0089
4	0.0754	0.0242	0.001	0.0018	0.0116	0.0095
5	0.06	0.012	0	0.003	0.013	0.009
M(Cx)	0.10	0.05	0.01	0.01	0.01	0.01
Percent	55.79	27.02	2.99	3.54	4.92	5.74

M(Cx): Marginal average contribution of variable.

valued by the students as these helped them to correct their misconceptions in dynamics fundamentals and concepts. After the completion of the project, they felt that their confidence and competence in the subject were greatly enhanced and attributed it to their better performance in the final examination. They even indicated that, in helping them to learn better, they wished to have a similar teaching approach used in the project, to be applied across other subjects.

DISCUSSION

The data collected from self-report questionnaire was treated as the primary source whilst lab observation and interviews with the instructor and students represented the qualitative aspect of the study for complementing the statistical analyses of data.

The statistically significant changes in intrinsic motivation (Mean, 0.44) and self-efficacy (Mean, 0.43) among the students in this study (Fig. 1), support research findings and predictions that, increased self-efficacy is accompanied by enhanced intrinsic motivation [1, 3, 7]. It is also evident by significant and increased correlation between intrinsic motivation and self-efficacy (0.56, 0.62). The data analyses are further supported by the qualitative analyses that the students enjoyed the learning and believed they could handle similar mechanical design problems. They also expressed favourable feelings and interests towards the subject especially the *Dynamics Project*.

While self-efficacy relates to one's personal confidence in his or her own capability on performing a specific task, intrinsic motivation brings about the focus on task/activity itself rather than reward. Both motivation constructs are highly desirable in academic settings for performance and achievement. Students in the study could see the relevance of their learning and therefore willing to spend more time and effort in the learning. Furthermore, the success of completing the tasks in their project enhanced their confidence in their capabilities of performing similar tasks. The findings therefore suggest that self-efficacy and intrinsic motivation of these students were greatly enhanced by the deployment of the intervention strategies. On assessing perceived gain in knowledge and skills of the subject among the students after completing the project, the statistical change is even more significant, (0.00, $p < 0.05$, with an increased mean of 33.28 after the project). The finding suggests that the perceived competence would enhance the confidence among the students at risk in the subject learning. This is consistent with the qualitative analyses that the students demonstrated a high level of confidence, after the completion of the study, in both dynamics topics and in the MTNSc2 subject.

Significant correlations among the variables suggest that deployment of the intervention strategies did exert a positive effect on student motivation and beliefs towards their learning. Similar findings on positive influence of diverse instructional strategies upon achievement-related behaviours have been cited in other literature [1, 3, 4, 15].

The notable difference in correlation between extrinsic motivation and persistence at pre-test and post-test (0.51, 0.66) implies that the students' effort in learning was driven by reward in terms of attaining a better grade. Secondly, high positive correlation is detected between learning goal and intrinsic motivation (0.75, 0.74) in both pre-test and post-test. Interestingly, the dominance analysis also indicates learning goals as the predominant variable, followed by intrinsic motivation (Table 3). Research has indicated that students who adopt a learning goal as their achievement motivation tend to seek challenging tasks, increase their competence and find their tasks intrinsically rewarding [3, 11]. The finding suggests that the students seemed to possess positive motivation towards learning, both before and after the study. Furthermore there is a relatively significant correlation between extrinsic motivation and self-efficacy (0.60, 0.61). The latter suggests that perceived capability of the students was enhanced by their accomplishments in the project. The finding supports the academic motivation research in which rewards enhance efficacy with progress in learning [6, 11, 12]. Collectively, the correlation results seem to suggest that the motivation level of the students might not be the contributing factor to their academic underachievement. This finding is in contrast with the general perception among faculty staff in the school that students at risk lack motivation in learning. The qualitative analyses of the data reveal and confirm that students in this study were sufficiently motivated in their learning, such that their confidence and competence in the MTNSc2 subject were greatly enhanced subsequently via the instructional intervention strategies.

Another interesting finding that has emerged in this study is the relatively weak correlation between self-regulation with the rest of the variables at pre-test and post-test. Self-regulation is a multidimensional skill in which one sets goals, uses strategies to attain the goals, and monitors the acquisition of those goals. Positive effects of self-regulation on academic achievement are well documented [13, 14].

The low correlation of self-regulation with other motivation variables in this study suggests that the students may lack self-regulatory skills. This deficit among the students could be a contributing factor for their academic underachievement.

CONCLUSIONS

It is important to reiterate that deployment of the instructional intervention strategies did bring about significant changes in self-efficacy and intrinsic motivation among the students at risk, perceived gain in knowledge and skills of the subject and positive correlations among various aspects of motivation. The results of this study support research of similar studies on positive and beneficial effects of instructional intervention programs.

A salient feature in this study is the student interview, which yields important insights and understanding of the students about their feelings, thoughts, expectations and concerns in learning, both in the MTNSc2 subject as well as other subjects in general. Such important information might have otherwise gone unnoticed as it was not captured in the self-report questionnaire. The qualitative data collected during interviews indeed complement the statistical analyses.

An interesting and incidental finding in the study is that the results seem to suggest that academic underachievement among the students at risk might not be due to the lack of motivation in learning. During the interviews, the students stressed that the greatest hindrance to their learning engineering subjects was in their difficulty in perceiving relevance of the subjects. Another possible contributing factor to underachievement is the finding which suggests deficit in self-regulatory skills among the students. The overall findings of this study bear several important implications for teaching.

Implications for teaching

As deployment of instructional intervention strategies in this study and similar studies found in literature are effective in enhancing achievement-related behaviours, it can be adopted to improve instructions in helping students learn better, particularly for students at risk who need more instructional support and encouragement.

To help students overcome the difficulty in perceiving relevance of the subject, it is essential that more instructional efforts be aimed at providing real-world experience, examples and case studies as well as providing a system perspective instead of topical ones in the subject understudied. These will help students in seeing the value or worthiness of the subject and thereby promote meaningful learning.

The first author was greatly impressed by the usefulness of student interviews in the study for obtaining far more information about the students than the self-report questionnaire administered earlier. The implication is that to help instructors enhance their teaching, they need to take time to talk to their students to elicit more understanding of their learning needs and concerns.

As indicated by the results of this study, it is inappropriate for one to perceive or assume that students at risk are always less motivated to learn and attribute this to their academic underachievement. Improved instructions on the part of instructors and self-regulatory skills acquired on the part of students could go a long way towards academic success of students.

While self-regulation forms an important and integral part of life-long learning skills, the detailed discussion of it is beyond the scope of this paper. Nonetheless, the skill training can be introduced as part of a freshmen program in a general studies module on generic learning strategies. It can later be embedded as specific learning strategies in subject learning.

REFERENCES

1. M. Bong, and R. E. Clark, Comparison between self-concept and self-efficacy in academic motivation research, *Educational Psychologist*, **34**, (1999), pp. 139–154.
2. D. R. Haws, Self-efficacy and the evaluation of instruction, *Ann. Conf. Proc. American Society for Eng. Educ.*, (1999).
3. J. D. Nichols, and W. E. Utesch, An alternative learning program: effects on student motivation and self-esteem, *J. Educ. Res.*, **91**, (1998), pp. 272–279.
4. F. Pajares, Current directions in self-efficacy research, in M. Maehr and P. R. Pintrich (eds.) *Advances in Motivation and Achievement*, Vol. 10, (1997), pp. 1–49. Greenwich, CT: JAI Press.
5. D. H. Schunk, Self-efficacy and academic motivation, *Educational Psychologist*, **26**, (1991), pp. 207–231.
6. A. Bandura, Social foundations of thought and action: a social cognitive theory, Eaglewood Cliffs, NJ: Prentice-Hall, (1986).

7. F. Pajares, Self-efficacy beliefs in academic settings, *Review of Educational Research*, **66**(4), (1996), pp. 543–578.
8. A. Bandura, Self-efficacy: toward a unifying theory of behavior change, *Psychological Review*, **84**, (1977), pp. 191–215.
9. G. Lim. S. Y. Tay, K. S. Chua, L. T. Lim, L. H. Hong, S. Rohana, B. L. Tan, P. Khaw, and S. Joseph, A proposed framework to enhance student motivation and learning attitude, in *Promoting Good Teaching Practice in Engineering Education*, Temasek Engineering School, Temasek Polytechnic, Singapore, (2000).
10. P. M. Yaeger, R. M. Marra, G. L. Gray, and F. Costanzo, Assessing new ways of teaching dynamics: an ongoing program to improve teaching, learning and assessment, *Ann. Conf. Proc. American Society for Eng. Educ*., (1999).
11. K. Yip, Goal orientation and its impact on student affect: some findings from a Singapore sample, *Singapore Journal of Education*, **12**(2), (1992), pp. 88–92.
12. J. Biggs, Motivating Learning, in J. Biggs and D. Watkins (eds), *Classroom Learning: Educational Psychology for the Asian Teacher*, Prentice-Hall, Simon & Schuster (Asia) Pte Ltd, (1995).
13. B. J. Zimmerman, Dimensions of academic self-regulation: a conceptual framework for education, in D. H. Schunk and B. J. Zimmerman (eds), *Self-regulation of Learning and Performance: Issues and Education Applications*, Hillsdale, NJ: Erlbaum, (1994).
14. B. J. Zimmerman, and M. Martinez-Pons, Development of a structured interview for assessing student use of self-regulated learning strategies, *American Educational Research Journal*, **23**, (1986), pp. 614–628.
15. J. Ingham, and W. R. McShane, Academic skills seminar: a two-year analysis of an intrusive intervention for freshmen on probation, *Ann. Conf. Proc. American Society for Eng. Educ*., (1998).

Grace Lim is the Principal Learning Technologist. She was the Senior Instructional Designer at Temasek Engineering School, provided consultancy and training to faculty staff on good teaching practice and e-learning. She obtained her M.Ed. from University of Sydney (Australia), majoring in Educational Psychology and Computers in Education. Her area of work and professional interests include human learning, hypermedia design and courseware development, and utilisation of computers in education. She has been publishing papers on using technologies in education.

K. S. Chua is a lecturer under the Division of Diploma in Mechatronics in Temasek Engineering School. He obtained his M.Sc. degree from the University of Manchester Institute of Science and Technology (U.K.), majoring in Solid Mechanics. He has been teaching at the Polytechnic for the last 6 years, supporting mainly mechanical engineering and design subjects. Prior to his current post, he was a Principal Engineer in an aerospace company where his professional expertise was in Aircraft Structural Design and Analysis.

K. Y. Wee is a lecturer in Quality Engineering, Statistics and Analysis, under the Division of Diploma in Quality Engineering and Management/Diploma in Business Process and Systems Engineering in Temasek Engineering School. He obtained his M.Sc. from the National University of Singapore. Prior to his teaching post, he worked as a Quality Practitioner in the electronics industry.