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Hypermedia Instruction and Learning Outcomes at Different Levels of Bloom's Taxonomy of Cognitive Domain*

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The paper focuses on the investigation of a relationship between hypermedia and different cognitive levels of learning, as defined by Bloom's Taxonomy of educational objectives. Student performance overall, as well as at the lower cognitive categories, corresponding to knowledge acquisition and routine application stages of learning, was significantly better when hypermedia instruction was used. There was also evidence that low ability learners benefited from hypermedia more at the lower cognitive categories, while high ability learners benefited more at the higher cognitive categories. While a review of the educational literature on the subject found few relevant studies, their results support these conclusions. The paper also discusses limitations of the analysis and makes recommendations for the future study.

INTRODUCTION

We live in a *global information society*, where computers are essential tools for university students and faculty alike. Leading engineering educators have long recognised that needs of today's students require pedagogy more effective than the traditional *sage-on-the-stage* approach. Adoption of learner-centred approaches is essential to improving learning outcomes, better recruitment and retention in engineering [1-3]. It also helps meet accreditation requirements [4]. Furthermore, it equips graduates with tools to cope with, and adapt to, an ever-changing workplace that demands life-long learning [5].

Yet university teaching, especially in engineering, is still largely untouched, not only by technology, but by modern educational philosophy as well. Engineering classrooms in 2000 too often looked exactly as they did in 1970 or 1940 [6]. Little evidence of anything that has appeared in educational articles and conferences in the past half-century could be found [7][8]. Faculty development is a particularly critical issue in engineering departments [9][10]. After being hired, new faculty members enter their classrooms without any idea of what to do there. Many never learn how to motivate students and facilitate learning at high cognitive levels. In the absence of any pedagogical training, they teach the way their teachers (who also never received any training) taught them [8].

Studies increasingly show that new media can effectively improve learning outcomes [11-14]. Low educational knowledge and low adoption rates of instructional technology among academics, particularly in engineering, are of concern [15]. Most academics consider themselves foremost as content experts, and adhere to the traditional, instructor-centred paradigm [3]. This can be expressed by the following attitudes: more is better; we teach content, not students, and if you know it, you can teach it [16].

However, allowances for learner differences are not made, learners are evaluated individually and sorted through competition, and evaluation schemes are usually limited to standard examinations [3]. Faculty development has low priority on campuses [17][18].

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As such, faculty lack the knowledge of educational theories and of instructional design necessary for an effective implementation of new media into teaching [15]. In order to meet the challenges facing engineering education, they need to embrace the following:

- The scholarship of teaching [6][7][10].
- Faculty development [19][20].
- Life-long and workplace learning [5].
- The adoption of instructional technology.

Workshops can introduce engineering faculty to learning theories and objectives, including Bloom's [21] and Gagné's [22] classifications of educational goals, behaviourist, cognitivist and constructivist theories [23-26], learner-centred pedagogy [1][3], active, collaborative and experiential learning [27][28], learning style models [27][29], etc. Theoretical framework and principles of good teaching practice, such as summarised by Chickering and Gamson in their meta-analysis of 50 years of educational research, can be used as guidelines in instructional design and implementation of new media in academic courses [30-32].

The author previously demonstrated that a learning style model could be used to integrate hypermedia into teaching of an engineering course [29]. This resulted in improved achievement and positive attitudes towards technology-enhanced learning [33-35]. This article reports on the effects of hypermedia instruction on different levels of cognition, as described by Bloom's Taxonomy. It should be noted that hyper-media is an outgrowth of hypertext, and provides a non-linear, associative linking of text, images (graphics and video) and sounds.

BLOOM'S TAXONOMY OF COGNITIVE DOMAIN

Following the 1948 Convention of the American Psychological Association, a group of educational psychologists at Harvard University led by Benjamin Bloom began the task of classifying educational goals and objectives to create a framework for organising the various learning activities. This became taxonomy including three overlapping learning domains: cognitive, affective and psychomotor.

Cognition is an intellectual process by which knowledge is gained from perception or ideas. The cognitive domain relates to thinking, knowledge acquisition and knowledge application, and, as such, it is the domain of most interest to educators. The affective domain relates to emotions, attitudes and values. The psychomotor domain relates to mastering physical skills, coordination, etc. Bloom's Taxonomy of Cognitive Domain is a way to classify the variety of educational objectives that are related to what and how we know. It was published in 1956 and has become a classic cited by most subsequent books on education [21].

Bloom identified six levels of learning, which represented increasing levels of cognitive complexity. The lowest level is a simple recognition of facts, labelled *knowledge*. Increasingly more complex and abstract mental levels are labelled c*omprehension*, *application*, *analysis*, *synthesis* and *evaluation* [21]. Each level is presumed to encompass those below it, so for example, analysis can only occur after the ability to apply understanding of factual knowledge has been accomplished. The first three levels are considered foundation thinking, which are used as a basis for the last three levels, considered higher level thinking. Associated with each level are certain learning outcomes, typically expressed by verbs such as *recall*, *draw*, *calculate*, *categorise*, *design*, *assess*, etc. A multitude of resources on Bloom's Taxonomy can be found on the World Wide Web (WWW) [36].

The enduring value of the taxonomy lies in its common sense assumptions, such as that learning should avoid heavy reliance on memorisation, and in a suggestion of a hierarchy from simple to more complex mental processes. However, many considerations were also brought about since the original work was published. For example, prior knowledge may affect what level skills learners may actually use [37]. Since expertise is defined largely in terms of knowledge base, tasks that require high level thinking in novices may be an automatic behaviour for experts.

Reclassifying the first level of taxonomy as *recall* was suggested as more appropriate than *knowledge*, since knowledge varies from concrete and specific to complex and abstract [38]. Others suggested that there should only be three broad categories, namely:

- Recall;
- Comprehension and routine application;
- Non-routine application, analysis, synthesis and evaluation [12].

Traditional assessment methods make it difficult to evaluate skills at higher levels of the taxonomy.

Recently, a reclassification of knowledge levels into a two-dimensional framework was proposed [39]. This promises to assist educators in distinguishing more closely between what they teach and what they assess, and to help in objective testing of higher learning outcomes. The six levels of taxonomy are renamed using the matching verb, with the two highest levels reversed: *remember*, *understand*, *apply*, *analyse*, *evaluate*, and *create* [39]. Create is now the highest level of learning, as evaluation is considered to precede any generative process. Another dimension is introduced as *factual, conceptual*, *procedural*, and *metacognitive* knowledge (metacognition, an area of cognition that draws from a number of different perspectives, is the study of how we develop knowledge about one's own cognitive system, and how we can be most efficient during the process of learning). This framework highlights the fact that learning levels are not always sequential and that, contrary to Bloom's assumptions, it is sometimes possible to operate on a *higher* cognitive level without fully mastering the *lower* level skills.

Bloom's Taxonomy and Engineering Education

Wankat and Oreovicz provide a good example of an adaptation of Bloom's taxonomy to the needs of engineering education [2]. In this context, *recall* entails routine information, definitions, descriptions and generalisations. *Comprehension* refers to understanding of technical representations, including translation, interpretation and extrapolation. *Application* refers to the use of abstractions in particular situations, such as rules, procedures and theories to perform computations, and to find solutions. *Analysis* refers to the breakdown of a problem to its constituent parts so that the hierarchy, connections and structure are explicit, the problem is clarified, and its properties determined. Many engineering problems fall into the analysis category, because complex engineering systems must be repeatedly analysed. S*ynthesis* involves putting together elements to form a whole system or solution. Many students find synthesis difficult because the process is open-ended and there is no single answer. Finally, *evaluation* involves making judgements about the value of material or methods for given applications, about satisfying specific criteria, or about using the standard of appraisal.

A major part of engineering work involves synthesis and evaluation. The former brings together problem solving, analysis, design, development of a plan, and implementation of the proposed solution. The latter may require external criteria such as economics or environmental impact.

In most engineering problem-solving, determining the precise level of the taxonomy is difficult, as the use of several categories is typically required to complete an engineering task. Defining learning outcomes and designing objective tests so that higher-level thinking is in evidence is thus complicated. As many engineering educators point out, while teaching/learning process is purported to engage higher-level thinking and reasoning skills, standard evaluations usually rely on knowledge acquisition or routine knowledge-application [9][20][40]. Questions and projects that elicit synthesis and evaluative skills and deep learning strategies are under-represented [41][42]. It is said that we are not doing enough to encourage a deep approach to learning among engineering students [43].

Hypermedia and Cognitive Levels

Over the past decade, research on hypermedia, including its effects on learning outcomes, has grown exponentially. Yet few studies attempt to investigate the effect of hypermedia instruction on different cognitive levels of learning, and the results are not conclusive. Differences were found in achievement between different learning styles on knowledge acquisition (lower-level), but no differences on knowledge application tasks [44]. Another study also found hypermedia most successful at enhancing learning at the lower cognitive categories [45].

However, others show that hypermedia help students gain not only basic knowledge, but also increase understanding [46]. It can also help students exercise cognitive skills from higher-level categories [47-50]. There is also some evidence that low ability learners benefit most in knowledge acquisition, while high ability learners benefit equally both on knowledge acquisition and knowledge application stage [51]. A recent comparative study of learning with hypermedia found that when interactive modules did not promote critical thinking, there was little increase in the performance of module users [52]. Yet when a mix of theory and practical information was used to convey difficult concepts, they significantly outperformed their peers who did not use the modules.

In summary, the results are still inconclusive, because evaluating cognitive engagement at different levels is difficult, especially from standard test-based assessments.

METHODS

The study took place in a sixth semester course in Process Control (ELE639) in an undergraduate electrical and computer engineering programme at Ryerson University, Toronto, Canada. It used archived examination data (1998-2002). Since 2000, learning style questionnaires for the Felder Model were also collected [29]. Final examination papers, stored in the Department for a period of five years, were the only accessible source of data available for *post-facto* comparisons.

In 1998, all students were instructed using conventional methods (n=77). In 1999, an experimental group (n=57) received hypermedia instruction, while a control group (n=37) received conventional instruction [33]. In 2000, the experimental and control samples were n=49 and n=45, respectively [34]. In both years, the hypermedia-instructed group performed significantly better than the control group. In 2001-2002, all students received hypermedia instruction, and the total cohorts were n=128 and n=137, respectively [53].

Student achievement was benchmarked using the Term Grade Point Average (TGPA) for the semester immediately preceding ELE639. Two equal-size populations of students were defined using the median TGPA score; Previously Above the Median (PAM) and Previously Below the Median (PBM).

Prior to the analysis of archived data, content of the examinations had to be assessed for the different cognitive levels. In order to avoid any perception of bias, a panel conducted the assessments. The panel, including four engineering professors specialising in control theory and an expert with a background in psychology, reviewed the examinations and classified all items according to Bloom's Taxonomy. The panellists discussed their classifications until consensus was reached.

Based on these classifications, student scores on examination and items corresponding to each of the cognitive levels were then computed. Reports for design laboratory projects from 2000-2002 were similarly classified and scored. In order to allow comparisons over time, the panel also assigned difficulty weights to all items evaluated. The average Pearson's correlation coefficient between individual assessments of the panellists was very strong (r=0.814) and statistically significant (0.05 level, two-tailed) confirming strong agreement among the panellists.

RESULTS AND DISCUSSION

In the previous study, introduction of hypermedia resulted in a visible improvement of academic performance of students [53]. In both years of the split-mode instruction (1999-2000), statistically significant group differences were observed between hypermedia-instructed and conventionally instructed students [33][34]. Analysis of covariance (ANCOVA) was employed to assess differences in examination scores. As is customary for the ANCOVA F-ratio statistic, the group means were adjusted for the covariate [54]. Group differences are shown in Table 1.

Table 1: ANCOVA statistics for group differences in final examination scores (1999-2000).

	1999		2000	
	Hyper	Conv.	Hyper	Conv.
No. of students	57	37	49	45
Pooled Mean	73.51		66.06	
Group Mean	76.07	69.57	63.64	58.71
Residuals	2.516	-3.876	2.346	-2.555
Pooled STD	11.728		11.712	
ANCOVA Statistic	F=7.155, df=1,92 p=0.009**		F=4.229, df=1,92 p=0.043*	

Academic Performance at Different Cognitive Levels

The panel confirmed the assertions that the problem-solving format of engineering exams does not allow for sufficient testing of higher levels of the taxonomy [9][20][40][41]. Furthermore, the panel found that higher-level cognitive skills are more likely to be assessed in design-oriented laboratory projects [40-42]. Between 1998 and 2001, close to 80% of the examination items represented cognitive levels of application and analysis (see Table 2), while close to 75% of the laboratory items represented analysis, synthesis and evaluation (see Table 3). Recall was not explicitly tested, and few items represented comprehension. This is not surprising, since the lowest levels of taxonomy were more appropriately addressed by short quizzes. Following the panel experts' assessment, the final examination in 2002 represented an attempt to balance problems at different cognitive levels, and included more items classified as synthesis (27%) and evaluation (9%).

Figure 1 shows a graphical representation of *cumulative* data from the archival analysis of the scores at different cognitive levels of conventionally instructed (1998-2002, n=159) and hypermedia-instructed (1999-2002, n=371) cohorts. Table 4 shows ANOVA results for cumulative (1998-2002) group differences and Table 5 shows ANOVA results for the two years where direct comparisons were available because of the split-mode instruction (1999-2000). To allow time-series comparisons, final examination scores were also adjusted for difficulty.

Regardless of the mode of instruction, scores were higher at the lower levels of taxonomy than at the higher levels. Statistically significant differences were observed overall at the combined lower and higher levels (2 and 3; and 4, 5, and 6, respectively, with no questions at level 1), and at application and analysis

Table 2: Bloom's Taxonomy - examinations (1998-2001).

Year	Recall	Comprehension	Application	Analysis	Synthesis	Evaluation
1998	-	6%	75%	19%	-	-
1999	-	4%	52%	30%	14%	-
2000	-	4%	58%	21%	10%	7%
2001	-	12%	48%	24%	16%	-
2002		17%	26%	21%	27%	9%

Table 3: Bloom's Taxonomy - laboratory reports (2000-2001).

Year	Recall	Comprehension	Application	Analysis	Synthesis	Evaluation
2000	-	10%	7%	25%	40%	18%
2001	-	12%	25%	25%	25%	13%
2002	-	12%	13%	21%	37%	17%

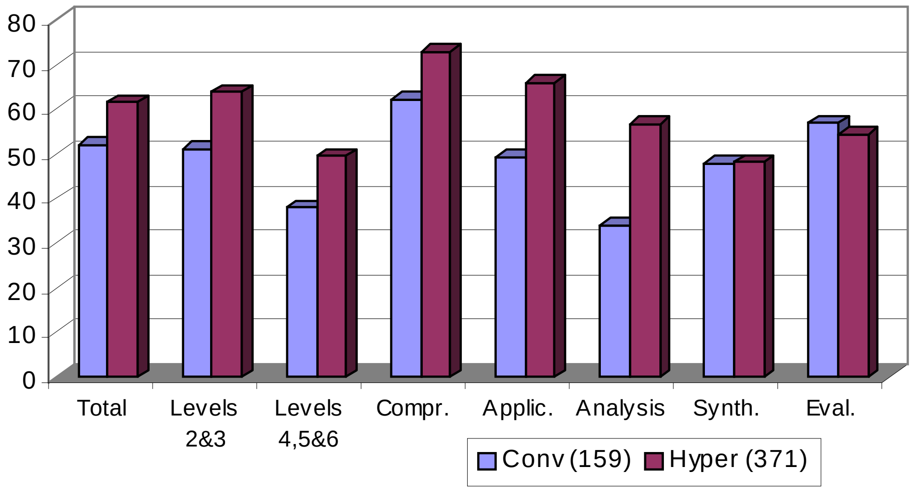

Figure 1: Final examination data (1998-2002) – achievement at different levels of Bloom's Taxonomy; scores adjusted for difficulty; conventional (n=159) vs. hypermedia (n=371).

levels. This leads to a conclusion that although differences were not *consistently* statistically significant at individual levels, it is probably attributable to the lack of statistical power, ie the size of the sample, and relatively few items on the examinations belonging to the comprehension, synthesis and evaluation categories, as shown in Table 2.

Relatively higher scores at the synthesis and evaluation levels than at the analysis level, as shown in Table 5, could be an artefact associated with the low number of questions at those two levels. Alternatively, however, this observation could also support assertions in the recent second edition of the Taxonomy highlighting the fact that learning levels are not always

Table 4: Bloom's Taxonomy levels - examinations (1998-2002); conventional (n=159) vs. hypermedia (n=371).

	HYPER (n=106)	CONV (n=82)	ANOVA
Total	61.3%	52.0%	F=65.455, df=1,528, p=0.0005**
Levels 2 & 3	63.7%	51.2%	F=107.16, df=1,528, p=0.0005**
Levels 4, 5, & 6	49.5%	37.9%	F=50.81, df=1,528, p=0.0005**
Level 2: Compr.	72.9%	62.3%	F=26.351, df=1,528, p=0.0005**
Level 3: Application	65.8%	49.2%	F=153.90, df=1,528, p=0.0005**
Level 4: Analysis	56.7%	34.0%	F=140.79, df=1,528, p=0.0005**
Level 5: Synthesis	48.0%	47.8%	F=0.003, df=1,451, p=0.956
Level 6: Evaluation	54.2%	56.9%	F=0.384, df=1,229, p=0.536

** significant at .01 level (2 tailed); * significant at .05 level (2 tailed).

Table 5: Bloom's Taxonomy levels - examinations (1999-2000); split-mode instruction: conventional (n=82) vs. hypermedia (n=106).

	HYPER (n=106)	CONV (n=82)	ANOVA
Total	60.9%	56.0%	F=7.455, df=1,186, p=0.007**
Levels 2 & 3	61.6%	58.3%	F=4.075, df=1,186, p=0.045*
Levels 4, 5, & 6	57.1%	48.8%	F=10.485, df=1,186, p=0.001**
Level 2: Compr.	80.2%	77.4%	F=1.024, df=1,186, p=0.313
Level 3: Application	58.4%	47.8%	F=4.777, df=1,186, p=0.042*
Level 4: Analysis	52.5%	41.3%	F=12.603, df=1,186, p=0.0005**
Level 5: Synthesis	56.9%	47.8%	F=3.981, df=1,186, p=0.047*
Level 6: Evaluation	63.8%	56.9%	F=1.348, df=1,92, p=0.249

** significant at .01 level (2 tailed); * significant at .05 level (2 tailed).

sequential and that may be possible to operate on a *higher* cognitive level without fully mastering the *lower* level skills [39].

Relationship between Ability and Achievement at Different Cognitive Levels

Next, comparisons were made between PBM and PAM cohorts, representing those students who respectively performed below the cohort median and above the class median prior to registering in the course in the study. Membership in these two widely defined groups is then taken as an indicator of the general academic ability level. Table 6 shows ANOVA results for cumulative (1998-2002) group differences for previously lower-achieving (PBM) students, and Table 7 shows these results for the previously higher-achieving (PAM) students.

The same pattern as for the overall cohorts is seen. Hypermedia-instructed cohorts significantly performed better than the conventionally instructed cohorts did overall at the combined levels, and at comprehension, application and analysis, ie lower cognitive levels. The differences were insignificant at the two highest

Table 6: ANOVA statistics for cumulative data of examination scores at different levels of Bloom's Taxonomy for the PBM category (1998-2002); scores adjusted for difficulty.

	HYPER (n=106)	CONV (n=82)	ANOVA
Total	57.6%	46.3%	F=53.655, df=1,264, p=0.0005**
Levels 2 & 3	60.9%	47.1%	F=68.003, df=1,264, p=0.0005**
Levels 4, 5, & 6	44.5%	32.8%	F=29.830, df=1,264, p=0.0005**
Level 2: Compr.	71.2%	59.5%	F=14.641, df=1,264, p=0.0005**
Level 3: Application	62.3%	45.2%	F=833.06, df=1,264, p=0.0005**
Level 4: Analysis	51.3%	29.0%	F=68.656, df=1,264, p=0.0005**
Level 5: Synthesis	42.7%	38.0%	F=1.080, df=1,225, p=0.300
Level 6: Evaluation	47.9%	60.5%	F=3.589, df=1,114, p=0.061

** significant at .01 level (2 tailed) * significant at .05 level (2 tailed)

Table 7: ANOVA statistics for cumulative data of examination scores at different levels of Bloom's Taxonomy for the PAM Category (1998-2002); scores adjusted for difficulty.

	HYPER (n=106)	CONV (n=82)	ANOVA
Total	65.1%	57.9%	F=23.707, df=1,262, p=0.0005**
Levels 2 & 3	66.4%	55.3%	F=46.488, df=1,262, p=0.0005**
Levels 4, 5, & 6	54.7%	43.1%	F=25.748, df=1,262, p=0.0005**
Level 2: Compr.	74.7%	54.9%	F=11.816, df=1,262, p=0.001**
Level 3: Application	69.2%	53.2%	F=81.146, df=1,262, p=0.0005**
Level 4: Analysis	62.2%	39.2%	F=83.163, df=1,262, p=0.0005**
Level 5: Synthesis	53.3%	57.5%	F=0.929, df=1,224, p=0.336
Level 6: Evaluation	60.9%	54.1%	F=1.446, df=1,113, p=0.232

** significant at .01 level (2 tailed) * significant at .05 level (2 tailed) levels. In both categories (PBM and PAM), scores were higher at the lower cognitive levels and lower at the higher levels. Figure 2 shows the score difference between PAM and PBM groups in average final examination scores overall as well as at the different cognitive levels (cumulative data 1998-2002).

The PAM-PBM gap in the overall examination, as well as overall laboratory scores, was reduced for the hypermedia cohorts when compared with the conventional cohorts. There was a significant reduction in the examination scores at comprehension and application levels, with the PAM-PBM gap at the application level comparable for both cohorts (Figure 2). A reduction also occurred at the synthesis level, but not at the evaluation level. In fact, conventionally instructed PBM students had higher average scores than the PAM students did at the evaluation level. This is most likely random and not representative, an artefact of the very few items at the evaluation level.

Thus, it can only be concluded that there was a definite reduction of the PAM-PBM differences at the lower cognitive levels of comprehension and application, and no reduction at the analysis level. The results for the two highest levels were inconclusive because of the small number of examination items at these levels, presented in Table 2. As seen in Figure 3, for the laboratory projects, with 60-80% of items at the higher cognitive categories, the reduction in PAM-PBM differences occurred both at the lower (application) as well as at the higher (analysis and synthesis) cognitive levels. Unfortunately, the observations at the individual cognitive levels may not be reliable due to the small sample size for the conventional cohort (n=45, 2000 only) in the comparisons.

Figures 2 and 3 show that, regardless of the environment, the differences between higher achieving (PAM) and lower achieving (PBM) students are less pronounced at the lower cognitive levels. Reductions

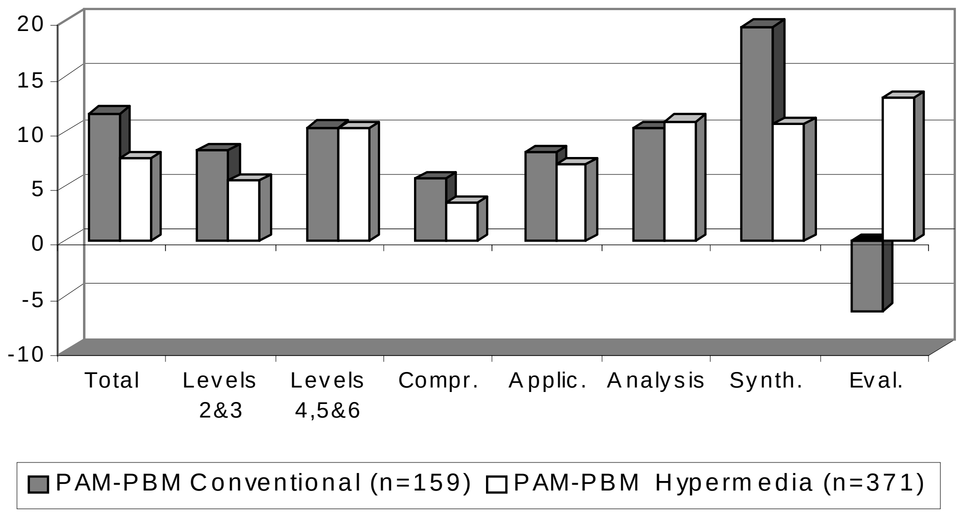

Figure 2: PAM-PBM differences in final examination scores at different cognitive levels of Bloom's Taxonomy.

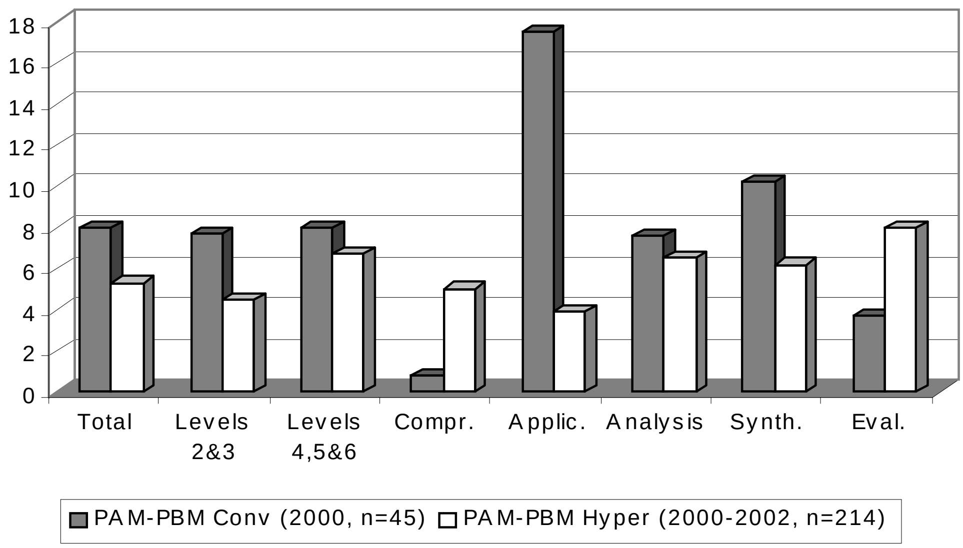

Figure 3: PAM-PBM differences in laboratory project scores at different cognitive levels of Bloom's Taxonomy.

that occur in the PAM-PBM score gap in the hypermedia-instructed cohorts, as compared with the conventionally instructed cohorts, are also more pronounced at the lower cognitive levels.

Relationship between Learning Styles and Achievement at Different Cognitive Levels

The literature on individual learner differences suggests that differences in learner ability, a pronounced individual trait, account for a large portion of variance in performance with hypermedia [55][56]. Another individual difference is accumulated knowledge and prior experience, ie differentiation between novices and experts. Significant differences are observed between novices and experts in achievements with hypermedia, as well as in navigation patterns and complexity of tasks [57-59].

Unlike learner ability, which accounts for a large variation in academic achievement, learning styles seem to be a secondary effect on academic achievement [60]. This should be expected, given an implied level of academic ability and cognitive flexibility at which university students must operate to be successful. In the author's previous study, the Felder model of learning styles was used [29]. The model focuses on aspects of learning styles significant in engineering education, and is very popular among engineering educators. The accompanying psychometric instrument, the Index of Learning Styles, has four bipolar scales: processing (active/reflective), perception (sensing/intuitive), input (visual/verbal), and understanding (sequential/global) [61].

In the 1999-2002 study, the author found statistically significant differences in Cumulative Grade Point Averages (CGPA), based on approximately 30 courses, between reflective and active students and between intuitive and sensing students. In the traditional teaching environment, represented by the CGPA score, reflective and intuitive students had significantly higher average CGPA scores than their active and sensing counterparts did [3][16]. This is consistent with the assertions in the literature that students with learning style preferences not supported by the traditional instruction are at a greater risk of poor performance and even dropping out [62-64].

Statistically significant differences in the *distributions* of learning styles between the previously lower-achieving (PBM) and the previously higher-achieving (PAM) students were also found [53]. If the learning style preferences had no effect on the achievement, it could be expected that for each style or a grouping of styles, 50% of its members would be performing Below-the-Median, while the other 50% would be performing Above-the-Median. Table 8 shows PBM-PAM distributions, representing the conventional environment of the four scales of the model. Students with active, sensing, visual and sequential preferences were over-represented (membership of more than 50%) in the previously lower-achieving group (PBM). Differences in distributions for two out of the four scales were statistically significant, and for the remaining two were almost significant.

For comparison, Table 9 shows BM-AM distributions in the course scores representing hypermedia-enhanced environment. Differences in distributions were no longer significant for any of the scales. Table 9 provides evidence that hypermedia-enhanced instruction supports a wider range of learning styles and thus provides a scaffold for the students with learning styles not well supported by the conventional teaching/learning environment.

Table 8: Distribution of style modalities between PBM and PAM students (2000-2002 data, n=338) in %.

	Ref	Act	Int	Sen	Ver	Vis	Glo	Seq
PBM	45	53	45	53	38	52	44	54
PAM	55	47	55	47	63	48	56	46
Chi-Square	χ^2 =3.485, df=1, p=0.062		χ^2 =3.293, df=1, p=0.070		χ^2 =7.316, df=1, p=0.007**		χ^2 =6.900, df=1, p=0.009**	

**Statistically significant at 0.01 level, 2-tailed.

Table 9: Distribution of style modalities between BM and AM students in hypermedia environment in the study (2000-2002 data, n=298) in %.

	Ref	Act	Int	Sen	Ver	Vis	Glo	Seq
PBM	46	49	45	50	46	48	47	49
PAM	54	51	55	50	54	52	53	51
Chi-Square	χ^2 =0.411 df=1, p=0.522		χ^2 =1.406, df=1, p=0.236		χ^2 =0.178, df=1, p=0.673		χ^2 =0.180, df=1, p=0.671	

In this study, distributions of learning styles were computed with respect to median values for scores representing the combined lower (2 and 3) and higher (4, 5 and 6) levels of Bloom's Taxonomy. As Table 9 shows, students with the reflective, intuitive and global modalities were slightly over-represented in the Above Median group in CG scores (combined 2000-2002 hypermedia-instructed cohort, n=298), at 54%, 55% and 53%, respectively. Distributions of all other modalities were within 1-2% of the 50%-50% equilibrium.

At the higher cognitive level (4,5 and 6, combined), the distributions changed very little, with a 1-2% increase for the reflective, intuitive and sequential modalities, and a 1-2% drop for active, sensing, visual, verbal and global students. The changes were not statistically significant.

The sample size was most likely large enough to ensure that type 2 error did not occur (ie missing the existing relationship). This could be taken as further evidence of the hypermedia instruction accommodating a wider range of learning styles, supporting previous findings [53]. The case would have been much stronger if differences in any scores corresponding to different levels of Bloom's Taxonomy were found between the different combinations of learning styles in the conventionally instructed cohort. However, that was not the case. The available sample (2000, n=40) was too small to allow any meaningful comparisons with the hypermedia-enhanced environment with respect to an interaction of learning styles and achievement at the different levels of cognitive domain.

CONCLUSIONS AND RECOMMENDATIONS

The study revealed that over the years, problem-solving examinations in the course consisted mostly of items representing application and analysis level, while the higher-level thinking was mostly tested through laboratory design projects. This insight was used in 2002 to widen the range of examination items across different cognitive levels, including more items classified as synthesis and evaluation.

Since its introduction in 1999, hypermedia instruction significantly improved examination performance at the application and analysis levels of Bloom's Taxonomy, as well as the overall examination (and course) performance, when compared with the conventionally instructed cohort. Regardless of the mode of instruction (ie hypermedia or conventional), the scores were higher at the lower cognitive levels than at the higher cognitive levels. The author's previous study showed that, while on average the overall performance of the previously lower-achieving (PBM) learners was still lower than that of their higher-achieving (PAM) peers, PBM students generally benefited from hypermedia more [53]. This was evident in a reduced gap between average course scores of PAM and PBM groups, as compared with their prior achievement, measured by the TGPA score. This reduction occurred in the hypermedia cohorts only and not in conventionally instructed ones.

In the current study, the analysis of the examination scores suggested that most of the gains of the PBM students occurred at the lower levels of the taxonomy. There is some indication that a similar reduction occurred at the cognitive higher levels in the laboratory projects. However, that observation may not be entirely reliable because of the fact that project scores reflect a group effort, while the examination scores reflect the individual effort.

It can be thus concluded that the hypermedia-enhanced learning-teaching environment offers the lower-achieving students an immediate advantage that allows them to catch up somewhat with their higher-achieving peers. However, as the complexity of the problems (ie their cognitive level) increases, this is less evident. In both environments (ie hypermedia and conventional), the trend for the PAM-PBM difference is to increase as the level of cognitive complexity grows. Not surprisingly, this suggests that the higher-achieving students are better able to deal with more complex problems, regardless of the environment.

No meaningful analysis of the effect of learning styles on learning at different cognitive levels was possible. One of the study limitations was a relatively small sample size, reducing significantly the statistical power when dealing with eight distinct learning style modalities, two levels of achievement and six levels of cognitive complexity. Another limiting factor was the examination format, with emphasis on tasks on application and analysis levels.

Any future study would benefit from a larger sample size to increase the robustness of statistical analysis and from a more innovative examination format, covering a wider range of tasks at different cognitive levels. Investigation of the revised cognitive level classification framework is also suggested [39].

REFERENCES

1. Catalano, G.D. and Catalano, K.C., Transformation: from teacher-centered to student-centered engineering education. *J. Engng Educ.*, 88, **1**, 59-64 (1999).
2. Wankat, P. and Oreovicz, F., *Teaching Engineering.* New York: McGraw-Hill (1993).

3. Smith, K. and Waller, A., *Afterward: New Paradigms for College Teaching*. In: Campbell, W. and Smith, K. (Eds), New Paradigms for College Teaching. Edina: Interactions Book Co. (1997).
4. Baum, E., Engineering accreditation in the United States of America - Criteria 2000. *Proc. 2nd Global Congress on Engng Educ.*, Wismar, Germany, 17-20 (2000).
5. Chisholm, C.U., Sustaining engineering as a discipline against present and future global technological change. *Proc. 5th Baltic Region Seminar on Engng Educ.*, 61-65, Gdynia, Poland (2001).
6. Rugarcia, A., Felder, R.M., Woods, D.R. and Stice, J.E., The future of engineering education I: A vision for a new century. *Chemical Engng Educ.*, 34, **1**, 16-25 (2000), http://www2.ncsu.edu/unity/lockers/users/f/felder/public/Papers/Quartet1.pdf
7. Mehta, S. and Danielson, S., The scholarship of teaching: building a foundation before reaching the pinnacle. *Proc. 2000 ASEE Annual Conf. and Expo*., St Louis, USA, Session 1375 (2000), http://www.asee.org/conferences/search/default.cfm
8. Stice, J.E., Felder, R.M., Woods, D.R. and Rugarcia, A., The future of engineering education IV: Learning how to teach. *Chemical Engng Educ.*, 34, **2**, 118-127 (2000), http://www2.ncsu.edu/unity/lockers/users/f/felder/public/Papers/Quartet4.pdf
9. Nataraj, M. and McManis, K., Application of educational and engineering research to classroom teaching. *Proc. 2001 Inter. Conf. on Engng. Educ. (ICEE)*, Oslo, Norway, Session 8D6 (2001). http://ineer.org/Events/ICEE2001/Proceedings/papers/436.pdf
10. Wankat, P.C., Felder, R.M., Smith, K.A. and Oreovicz, F.S., *The Scholarship of Teaching and Learning Engineering*. In: Huber M.T. and Morreale, S. (Eds), Disciplinary Syles in the Scholarship off Teaching and Learning: Exploring the Common Ground. Washington, DC: AAHE/Carnegie Foundation for the Advancement of Teaching (2002).
11. Kulik, C.C. and Kulik, J.A., Effectiveness of computer-based instruction: an updated analysis. *Computers in Human Behavior*, 7, 75-94 (1991).
12. Kadiyala, M. and Crynes, B.L., A review of literature on effectiveness of use of information technology in education. *J. Engng Educ.*, 89, **2**, 177-184 (2000).
13. Spencer, K., Educational technology – an unstoppable force: a selective review of research into the effectiveness of educational media. *Educational Technology and Society*, 2, **1**, (1999), http://ifets.gmd.de/periodical/vol_2_99/spencer.html
14. Liao, Y.C., Effects of hypermedia on students' achievement: a meta-analysis. *J. Educ. Multimedia and Hypermedia*, 8, **3**, 255-277 (1999).
15. Zywno, M.S., Attitudes of engineering faculty towards technology-assisted instruction - a polemic. *World Trans. on Engng. and Technology Educ.*, 1, **1**, 47-50 (2002).
16. Weimer, M., *Improving Your Classroom Teaching*. Beverly Hills: Sage Publications (1993).
17. Boyer, E., *Scholarship Reconsidered: Priorities of the Professorate*. San Francisco: Jossey-Bass (1990).
18. Pedro, F., Transforming on-campus education: promise and peril of information technology in traditional universities. *European J. of Educ.*, 36, **2**, 175-187 (2001).
19. Brent, R., Felder, R.M., Regan, T., Walser, A., Carlson-Dakes, C., Evans, D., Malave, C., Sanders, K. and McGourty, J., Engineering faculty development: a multicoalition perspective. *Proc. 2000 ASEE Annual Conf. and Expo.*, St Louis, USA, Session 2630 (2000).
20. Felder, R.M., Rugarcia, A. and Stice, J.E., The future of engineering education V: Assessing teaching effectiveness and educational scholarship. *Chemical Engng Educ.*, 34, **3**, 198-207, (2000), http://www2.ncsu.edu/unity/lockers/users/f/felder/public/Papers/Quartet5.pdf
21. Bloom, B.J., Englehart, M.D., Furst, M.D., Hill, E.J. and Krathwohl, D.R., *Taxonomy of Educational Objectives: The Classification of Educational Goals. Handbook 1: Cognitive Domain*. New York: David McKay (1956).
22. Gagné, R., *The Conditions of Learning*. New York: Holt, Rhinehart & Wilson (1965).
23. Skinner, B.F., *Technology of Teaching*. New York: Meredith Publishing (1968).
24. Valcke, M., Models for Web-based education: have we forgotten lessons learned? *Proc. 1999 Symp. Virtual University? Educational Environments of the Future*, Stockholm, Sweden (2001), http://vu.portlandpress.com/vu_ch5.htm
25. Bruner, J., *Toward a Theory of Instruction*. Cambridge: Harvard University Press (1966).
26. Vygotsky, L.S., *Thought and Language*. Cambridge: MIT Press (1962).
27. Kolb, D.A., Experiential learning: experience as the source of learning and development. Englewood Cliffs: Prentice Hall (1984).

28. Johnson, D.W., Johnson, R.T. and Smith, K.A., *Active Learning: Cooperation in the College Classroom*. Edina: Interaction Book Co. (1991).
29. Felder, R.M. and Silverman, L.K., Learning and teaching styles in engineering education. *J. of Engng. Educ.*, 78, **7**, 674-681 (1988).
30. Chickering, A.W. and Gamson, Z.F., *Applying the Seven Principles for Good Practice in Undergraduate Education*. In: Chickering, A.W. and Gamson, Z.F. (Eds), New Directions for Teaching and Learning. San Francisco: Jossey-Bass, 47 (1991).
31. Chickering, A.W. and Ehrmann, S.C., Implementing the seven principles of good practice in undergraduate education: technology as lever. *American Assoc. for Higher Educ. (AAHE) Bulletin*, 49, **2**, 3-6 (1996).
32. Zywno, M.S., Enhancing good teaching practice in control education through hypermedia instruction and Web support. *Proc. 2002 Inter. Conf. on Engng. Educ. (ICEE)*, Manchester, England, United Kingdom (2002).
33. Zywno, M.S. and Waalen, J.K., Analysis of student outcomes and attitudes in technology-enabled and traditional education: a case study. *Global J. of Engng. Educ.*, 5, **1**, 49-56 (2001) http://www.eng.monash.edu.au/uicee/gjee/vol5no1/Zwyno&Waalen.pdf
34. Zywno, M.S. and Waalen, J.K., The effect of individual learning styles on student outcomes in technology-enabled education. *Global J. of Engng Educ.*, 6, **1**, 35-44 (2002), http://www.eng.monash.edu.au/uicee/gjee/vol6no1/zywno.pdf
35. Zywno, M.S. and Kennedy, D.C., Student attitudes towards the use of hypermedia instruction and Web support in control education - a comparative study. *Proc. American Control Conf.*, Anchorage, Alaska (2002).
36. Krumme, G., Major Categories in the Taxonomy of Educational Objectives: Bloom, 1996 (2001), http://faculty.washington.edu/krumme/guides/bloom.html
37. Anderson, L.W. and Sosniak, L.A. (Eds), *Bloom's Taxonomy: A Forty-year Retrospective*. Chicago: National Society for the Study of Education (1994).
38. Paul, R., *Bloom's Taxonomy and Critical Thinking Instruction: Recall is Not Knowledge*. In: Willsen, J. and Binker, A.J.A. (Eds), Critical Thinking: How to Prepare Students for a Rapidly Changing World. Santa Rosa: Foundation for Critical Thinking (1995).
39. Anderson, L.W., Krathwohl, D.R. and Bloom, B.S., (Eds), *Taxonomy for Learning, Teaching and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. New York: Longman (2000).
40. Heywood, J., Problems in the design of assessment led curricula. *Proc. 29th ASEE/IEEE Frontiers in Educ. Conf.*, San Juan, Puerto Rico (1999), http://fie.engrng.pitt.edu/fie99/
41. Domin, D.S., A content analysis of general chemistry laboratory manuals for evidence of higher-order cognitive tasks. *J. Chemical Educ.*, 76, **1**, 109-112 (1999).
42. Kovalik, C.L. and Dalton, D.W., The process/outcome evaluation model: a conceptual framework for assessment. *J. Educ. Technology Systems*, 27, **3**, 183-194 (1998-1999).
43. Rowe, J.W.K., First year engineering students' approaches to study. *Inter. J. of Electr. Engng Educ.*, 39, **3**, 201-209 (2002).
44. Pillay, H., An Investigation of the effect of individual cognitive preferences on learning through computer-based instruction. *Educational Psychology*, 18, **2**, 171-182 (1998).
45. Hmelo, C.E., Lunken, E.Y., Gramoll, K. and Yusuf, I., Multimedia courseware for teaching dynamic concepts: assessment of student learning. *Proc. 25th ASEE/IEEE Frontiers in Educ. Conf.*, Atlanta, Georgia (1995).
46. Hill, M., Bailey, J.D. and Reed, P.A.S., Hypermedia systems for improving knowledge, understanding and skills in engineering degree courses. *Computers & Educ.*, 31, 69-88 (1998).
47. Jacobson, M.J. and Spiro, R.J., Hypertext learning environments, cognitive flexibility and the transfer of complex knowledge: an empirical investigation. *J. of Educational Computing Research*, 12, **4**, 301-333 (1995).
48. Cookman, C., A Computer-based graphics course and students' cognitive skills. *Journalism and Mass Communication Educator*, 53, **3**, 37-49 (1998).
49. Paolucci, R., the effects of cognitive style and knowledge structure on performance using a hypermedia learning system. *J. of Educational Multimedia and Hypermedia*, 7, **2/3**, 123-150 (1998).
50. Mayer, R.E., Multimedia aids to problem-solving transfer. *Inter. J. of Educ. Research*, 31, 611-623 (1999).
51. Crosby, M.E. and Inding, M.K., The influence of a multimedia physics tutor and user differences on the development of scientific knowledge. *Computers in Educ.*, 29, **23**, 127-136 (1997).
52. Henson, A.B., Fridley, K.J., Pollock, D.G. and Brahler, C.J., Efficacy of interactive Internet-based

education in structural timber design. *J. of Engng Educ*, 91, **4**, 371-378 (2002).
53. Zywno, M.S., Instructional technology, learning styles and academic achievement. *Proc. 2002 ASEE Annual Conf. and Expo.*, Montreal, Canada, Session 2422 (2002).
54. Wildt, A.R. and Ahtola, O., *Analysis of Covariance*. Sage University paper series on Quantitative Applications in Social Science, series no. 07-012, London: Sage Publications (1978).
55. Dillon, A. and Gabbard, R., Hypermedia as an educational technology: a review of the quantitative research literature on learner comprehension, control and style. *Review of Educ. Research*, 68, **3**, 322-349 (1998).
56. Weller, H.G., Repman, J., Lan, W. and Rooze, G., Improving the effectiveness of learning through hypermedia-based instruction: the importance of learner characteristics. *Computers in Human Behaviour*, 11, **3-4**, 451-465 (1995).
57. Chen, S.Y. and Ford, N.J., Modeling user navigation behaviours in a hypermedia-based learning system: an individual differences approach. *Knowledge Organization*, 25, **3**, 67-78 (1998).
58. Ford, N.J., and Chen, S.Y., Individual differences, hypermedia navigation, and learning: an empirical study, *J. Educ. Multimedia and Hypermedia*, 9, **4**, 281-311 (2000).
59. Reed, W.M., Ayersman, D.J. and Liu, M., The effects of students' computer-based prior experiences and instructional exposures on the application of hypermedia-related mental models. *J. Educ. Computing and Research*, 14, **2**, 185-207 (1997).
60. Ayersman, D.J., Reviewing the research on hypermedia-based learning. *J. Research on Computing in Educ.*, 28, **4**, 500-525 (1996).
61. Felder, R.M. and Soloman, B.A., Index of Learning Styles Questionnaire. North Carolina State University (2001), http://www2.ncsu.edu/unity/lockers/users/f/felder/public/ILSdir/ILS-a.htm
62. Cleary, B.A., Relearning the learning process. *Quality Progress*, 29, **4** (1996).
63. Felder, R.M, Reaching the second tier: learning and teaching styles in college science education. *J. College Science Teaching*, 23, **5**, 286-290 (1993).
64. Felder, R.M., Felder, G.N. and Dietz, E.J., The effects of personality type on engineering student performance and attitudes. *J. of Engng Educ.*, 91, **1**, 3-17 (2002).

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Małgorzata S. Żywno is a Professor in the Department of Electrical and Computer Engineering at Ryerson University in Toronto, Canada. She received her MEng degree in electrical engineering from the University of Toronto in 1990 and is currently in a doctoral programme at Glasgow Caledonian University in Glasgow, Scotland, UK, expecting to complete her degree in Spring 2003. Her teaching and research interests include control systems, system identification, and recruitment and retention strategies for women in engineering and, more recently, technology-aided pedagogy.

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