AC 2007-1608: A SUMMARY ANALYSIS OF ENGINEERING STUDENTS' INTERACTIONS WITH AN ONLINE LEARNING OBJECT IN THE CONTEXT OF THEIR LEARNING STYLES

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A Qualitative Analysis of Engineering Students' Interactions with an Online Learning Object in the Context of their Learning Styles

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Abstract

This is last in a series of three papers reporting on the results of a research project looking into differences in interactions of engineering students with a learning object. The object in question was a set of interactive online tutorials in introductory Process Control. The research project investigated the effectiveness of this learning tool and identified behavior patterns of engineering students with different learning styles that may affect their learning. The first paper in the series described a collaborative effort involved in developing the award-winning set of online tutorials. The second paper focused on the quantitative analysis of the volunteers' results, including distributions of learning styles, pre- and post-test scores, and the breakdown of learning gains according to Bloom's Taxonomy. This concluding paper focuses on the analysis of individual sessions where screen activity was videotaped and the volunteers commented aloud on their thought processes and choices as they navigated their way through the tutorials.

Background

The work of Richard Felder[2], an acknowledged authority on engineering education, points to a mismatch between learning styles of engineering students and the styles of instruction commonly used in engineering departments. Felder asserts that teaching in a style that is consistently not supportive of the majority of learners may result in poor achievement, increased dropout rates and a loss of diversity among future engineers that would greatly benefit the profession. He suggests a *balanced teaching style* addressing a wide range of learner preferences as most effective[1, 2]. In 1988 Felder developed, with help of psychologist Linda Silverman, a learning model that focuses on aspects of learning styles particularly significant in engineering education[2, 3]. The model classifies characteristics of the learners along four bipolar dimensions: Perception (Sensing-Intuitive), Input (Visual-Verbal), Processing (Active-Reflective) and Understanding (Sequential-Global). The Felder-Soloman Index of Learning Styles (ILS), a psychometric instrument associated with the model, is freely available online[4].

Multimedia and the Internet bring about a potential for dynamic visualizations of engineering concepts, interactivity and asynchronous communications. When implemented in the context of active learning, such tools support an expanded range of learning styles. Both authors have been using multimedia and online support to enhance active learning and visualization in their courses and to provide students with improved formative feedback and review of the learned concepts. Between 1999 and 2003, the principal author conducted a longitudinal classroom research study of the relationship between learning styles described by the Felder Model and learning outcomes in technology-rich environment. Published results showed improved outcomes both in cognitive[5, 6] and affective[7] domains. When compared with a control group taught traditionally, the experimental cohort had significantly better final scores, and the improvements were more pronounced among the students whose achievement scores prior to taking the course were below the cohort median.

Based on their ILS scales, Active, Sensing and Global students were found to be overrepresented in the previously lower-achieving group, but subsequently showed higher learning gains in the course. This lead the investigator to conclude that students with these modalities were a) the most disadvantaged in a traditional lecture room and b) that while interactive multimedia helped students with all modalities improve their scores, Active, Sensing and Global learners benefited the most. Other studies reached similar conclusions. For example, a study at the University of Texas, where interactive online tutorials were used to support Mechanical Engineering labs, also found larger improvements among the sections with access to the tutorials[8], as compared with the sections that did not use the tutorials. The study also found that Active and Sensing learners benefited more from the virtual labs than Visual learners did. These observations support Felder's assertion that Active, Sensing and Global learners are the main beneficiaries of a teaching style that includes a mix of different strategies going beyond the conventional, text-based, passive lecturing[1, 3].

Gains in learning outcomes observed in the principal author's longitudinal study were attributed to a more engaging environment where an expanded range of learning styles was supported. However, constraints placed on that study by the desire to minimize the disruptiveness of an action research conducted in the context of a real curriculum allowed for little direct observation of students' interactions with the multimedia materials used in the course. Such observations became the focus of a follow-up study, conducted in 2004 and reported here, with fifteen volunteers interacting with a set of online tutorials[9] that included videos of practical behaviors of various control systems, interactive animations and quizzes.

Previous Stages of Reported Study

The authors developed the set of online tutorials as an additional learning resource tool for undergraduate engineering students, covering five areas of an introductory course in Process Control. Assistance from the Digital Media Projects Office (DMP)[10] at Ryerson made it possible to implement Flash and streamed video technology to build the tutorials. The project was part of CLOE[11], a collaborative initiative between several Ontario universities to create an innovative infrastructure for joint development of multimedia-rich learning resources. It was an example of an interdisciplinary collaboration involving the DMP; an industrial partner, Quanser, Inc.[12] whose facilities were used in shooting video segments that illustrate practical behaviors of a variety of control systems; and peer review by faculty members from different engineering departments from Ryerson University and from Memorial University, Newfoundland. The module development was reported in the first paper of the series[13], while the second paper focused on the quantitative analysis of the results[14], including distributions of learning styles, pre- and post-test scores, and the breakdown of learning gains according to Bloom's Taxonomy[15].

Post-test results of a quiz completed by all participants showed statistically significant improvements for all participants as compared with the pre-test results. While the small sample size does not allow far-reaching conclusions from that observation alone, it is consistent with the framework developed by Felder and with the results of the previous longitudinal study[5, 6]. Learning gains at lower cognitive levels of Bloom's Taxonomy (i.e. recall, comprehension and application) were larger than at higher cognitive levels (i.e. analysis, synthesis and evaluation). This observation was again consistent with the previous work[16], and led the authors to conclude that the module seems to be more effective in helping students solidify their knowledge at the lower cognitive levels. Learning gains were observed for all individual learning styles according to the ILS scales, indicating that all students, regardless of their learning style, benefited from interactions with the on-line module. In particular, working with the module seems to have benefited the Sensing students, who not only had higher gain improvements overall, but actually had higher post-test scores in several categories.

Study Design and Hypotheses

The research protocol for the study was approved by the Ryerson Research Ethics Board. Student participation was voluntary, and all participating students were asked to sign an informed consent letter. Fifteen recent graduates, five from a Mechanical Engineering program, and ten from an Electrical Engineering program participated in this project. For the first part of the study, as previously reported[14], all students completed the ILS questionnaire, a multiple choice pre-test based on the control theory covered in the on-line module, a usability questionnaire, and a recorded usability focus group discussion.

The second part of the study consisted of individual sessions with the module lasting approximately one hour. Participants' screen interactions were videotaped and Talk Aloud Protocol (TAP) was used to record their comments. TAP is a method of collecting data from participants during a usability test where the participants verbalize what they are thinking as they complete a task. The participants were asked by an assistant to review the module and to comment on its content as well as on its usability features (e.g. ease of navigation, color scheme, choice of graphical and video components, etc.). The assistant would also occasionally prompt the participants to continue to speak out while going through the review. Subsequently, two of the recorded sessions turned out to have audio levels so low as to make them inaudible. All fifteen recordings were used to establish navigational patterns and type of screen activities, for which the audio recording was not required. However the lack of audio reduced the number of cases available for verbal protocol analysis to thirteen.

The module layout included several categories of topics that required different actions and were implemented using different media, thus making it easier to relate the time spent in these categories to a learning style. For the purpose of encoding the times spent browsing through different types of screens several categories were singled out for more detailed observation. They were Basic Concepts, a stand-alone tutorial containing an introduction to basic control concepts, and implemented using a mix of text, graphics, animations; Math, a combination of similarly named sections in each of the remaining four tutorials (Stability, Tracking, Disturbance Rejection and PID Control) and containing more advanced theoretical information, predominantly text and mathematical formulae with some graphs; Video, a combination of similarly named sections of the tutorials where several clips of streamed video of a real control system could be viewed; Interactive, a category that included all screens throughout the module's different sections where some interactions were required (e.g. click on a button in order to increase/decrease gain, etc.); and finally Quiz, a combination of similarly named review sections following each of the five tutorials, and providing the viewer with a "right"/"wrong" response to their choice of answer, an explanation why that was, as well as a total score for each quiz. Quiz screens were not counted in the Interactive category. Because many screens from Basic Concepts tutorial as well as from Math sections were also interactive, the sum of recorded times for all categories is not the same as the total observation time.

Videotapes of screen activity were next watched in order to encode the quantitative data as well as "verbalizations", i.e. continuous phrases relating to a specific event, problem or course of action. Some verbalizations consisted of a few words while some were two or three sentences long. Each tape was watched several times by both an assistant and one of the investigators to verify the encoding.

The quantitative data encoded were total duration of the interactions with the module; the length of time spent reviewing the tutorials as well as the quiz section; and the length of time spent browsing through each of the five established categories. Next, each screen visited by a participant was categorized as one of the following: Text - mostly text and formulae; Graphics - mostly graphics; Interactive - there was some interactivity involved on that screen, with quiz screens excepted; Total - total number of screens visited, with quiz screens excepted; and Video - number of video clips seen. Quick flipping through pages and other "navigational chatter" were ignored and only screens that seemed purposely visited for at least several seconds were included both in the time and in the screen count.

All verbalizations recorded during the observations were transcribed and encoded according to a set of agreed-upon categories. The three major categories of verbalizations were as follows:

- Confusion, a self-explanatory category, illustrated by such utterances as: "I'm kind of lost in what this whole screen is about…" or "I'm not quite sure what uh, skip intro means."
- Usability, a category of statements dealing exclusively with the ease of navigations, color schemes, font size, etc., illustrated by such utterances as: "And, uh, again the animation is very good, it makes it clear and uh, with the speed, and everybody's aware of the car and the

speed and how it goes, so uh, make things a lot better" or "Ah, the graph is kinda small, but uh, probably on the screen it's okay to read, but probably on a computer screen it's probably harder."

- Content, a category of verbalizations that dealt with purposeful studying of the module. This category included several sub-categories, as follows:
    - Navigation1, a statement of fact, or action is taken, illustrated by such utterances as: "Now we have menus back down here" or "Okay, I can click next, pretty easy to do."
    - Navigation2, where some strategizing or reasoning is evident, illustrated by such utterances as: "Okay, let's go through a different condition…" or "Now I'll see if I can continue by just arrowing out."
    - Text1, a verbalization associated with a mainly text or formulae screen, indicating lower level cognitive functions, such as reading out or paraphrasing information on the screen, illustrated by such utterances as: "Welcome to the tutorial" or "There's an under-damped definition."
    - Text2, a verbalization associated with a mainly text or formulae screen, indicating higher level cognitive functions, where some reasoning, problem-solving, inference or drawing conclusions is evident, illustrated by such utterances as: "So that's, this is the math page of the stable, okay, I understand now" or "The analytical things are uh, gonna remind me of a couple of things that I learned in controls. I, probably forgotten most of it, so this is a good thing."
    - Mix1, a verbalization associated with a screen that is a mix of graphics, video, interaction and text, indicating lower level cognitive functions, such as describing or paraphrasing information on the screen, illustrated by such utterances as: "Okay, it's good that it's highlighted, you can pick out what's being changed" or "Like I guess open loop and closed loop, and those are illustrated right underneath that screen."
    - Mix2, a verbalization associated with a screen is a mix of graphics, video, interaction and text, indicating higher level cognitive functions, where some reasoning, problem-solving, inference or drawing conclusions is evident, illustrated by such utterances as: "Okay, that's nice because you can compare the over-damped, then click under-damped, and, and I can see where the poles are and how I can, uh, the curve behaves", or "You can see all the helicopter response. It kind of makes sense when you look at the graph until is close to settled. Yeah, the videos give you a real life problem and you understand why the whole point of this is" or "This is by adding an additional pole, move, the graph moves from A to B, so you can tell the changes of what happens."

The module presented a wealth of different multimedia components impossible to study and review thoroughly during a one hour session. The participants were given a free reign in how they wished to approach the review so that the investigators could test their hypothesis that students with different learning styles were likely to exhibit different navigational patterns as well as to spend varying amounts of time browsing through different types of screens. The investigators also hypothesized that students with higher levels of academic achievement would manage to browse through more material, and be more curiosity-driven in their explorations of the module (as in "how do different features of this module help me in understanding control concepts"), as opposed to performance-driven explorations of the module (as in "if I review more quiz questions, it will help me improve my score on the post-test"). In order to capture these differences two subgroups were created as follows. A median GPA score for the experimental cohort was found (equal to 3.0 or an equivalent of a B-), and the seven students whose GPA scores were above the median cohort score were classified as Above-the Median, or AM, students, while the eight students whose GPA scores were below the median cohort score were classified as Below-the Median, or BM students.

Results and Discussion

Navigation Patterns and Screen Activities

A large variation of access times and screen numbers was observed. The average time spent on reviewing the module was 38.1 minutes (min. 12.4, max. 64) vs. 16.6 minutes studying the quiz (min. 0, max. 43.7). The average number of total screens viewed was 253.9 (min. 90, max. 461), including 100.3 for text screens (min. 46, max. 179), 73.3 for graphics screens (min. 20, max. 153), and 65.5 for interactive screens (min. 9, max. 159). The average number of video clips viewed was 14.8 (min. 3, max. 31). Table 1 shows time spent viewing different parts of the module as percentage of the total time.

Table 1: Time and Screen Activities

	Module Time/Total	Quiz Time/Total	Basics/ Module Time	Math/ Module Time	Video/ Module Time	Interactive/ Module Time
OVERALL						
Mean	0.703	0.297	0.361	0.105	0.119	0.185
Median	0.625	0.375	0.347	0.095	0.113	0.199
St. Dev.	0.256	0.256	0.141	0.072	0.057	0.049
AMONG BM STUDENTS						
Mean	0.576	0.425	0.328	0.107	0.105	0.166
Median	0.587	0.413	0.270	0.098	0.068	0.173
St. Dev.	0.239	0.239	0.161	0.086	0.071	0.043
AMONG AM STUDENTS						
Mean	0.849	0.151	0.400	0.103	0.135	0.206
Median	0.965	0.035	0.400	0.091	0.138	0.209
St. Dev.	0.200	0.200	0.115	0.059	0.037	0.050

AM students, compared with the BM students, spent more time reviewing the content of the module (mean of 46.1 minutes vs. 31.2 minutes), and less time reviewing the quiz (8.6 minutes vs. 23.7 minutes). The repeated measures analysis of variance (ANOVA) showed statistical significance in both cases, $F(1,13)=5.664$, $p = 0.033$, and $F(1,13)=5.398$, $p = 0.037$. The AM students also spent significantly more time in the Basic Concepts section, viewing video clips and more time on interactive screens, with ANOVA results of $F(1,13)=6.021$, $p = 0.029$; $F(1,13)=10.235$, $p = 0.007$; and $F(1,13)=6.086$, $p = 0.028$, respectively. Six out of eight students belonging to the lower achieving group, BM, spent between 40% and 80% of their time reviewing the quiz section of the module in order to prepare for the post-test, rather than exploring the module. On the other hand, five out of the seven students belonging to the higher achieving group, AM, on average spent only 4% of their time on the quiz section.

Table 1 seems to support the authors' hypothesis that the higher-achieving students were more curiosity-driven and thus would explore the module in greater depth, while the lower achieving students were more performance-oriented, and would spend more time reviewing the quiz. However, there may be an alternative interpretation of these differences, a novelty factor. All eight BM students were from Electrical Engineering, and thus had worked with the module one semester prior to the experiment, as it was used in a Control course they all took. On the other hand, all but two AM students were from Mechanical Engineering, and thus had never seen the module before. Therefore it is likely that the Mechanical Engineering students were prone to a "wow" factor and spent more time on the video, on interactive features, and on the module in general. Indeed, many of their comments showed that they were clearly fascinated by the video and interactive possibilities of the module, using comments such as "it's excellent with the video", "I'm pretty impressed with the video", "I like that video, it's pretty good", "that's great animation there", etc. On the other hand, Electrical Engineering students, who were similarly impressed with the module at the time of its introduction into the course, tended to accept these features as a given during the experiment and possibly skip them as familiar. They were also familiar with the video clips, most of which they saw in class, and thus were less likely to look at them again. Given only a vague instruction to explore the module, they had less incentive to do it in depth or to offer richer verbalizations. Thus it is possible that six out of the eight BM students opted for more performance-driven explorations (i.e. spending most of their time reviewing the quiz) because of their familiarity with the module.

Differences consistent with the construct of the Felder Model were observed in navigation patterns between learners with different learning styles. For example, Reflective learners visited more pages of text (mean of 122.8 vs. 89.0 for Active learners), Sensing learners visited more pages overall (mean of 270.9 vs. 219.8 for Intuitive learners), Sequential learners spent more time in the very first tutorial, Basic Concepts (mean of 14.7 minutes vs. 11.5 for Global learners), and less time viewing video clips (3.6 minutes vs. 5.9 minutes for Global learners). They also saw more pages (mean of 274.6 vs. 212.4 for Global learners). As well, the Sensing score was correlated with the number of graphics pages visited, the number of video clips seen, the number of interactive pages visited, and the number of text screens visited but only the last correlation reached the level of statistical significance (Pearson's $r = 0.536^*$, $p = 0.039$, statistically significant at 0.05 level). Positive correlations were also found between the Visual score and the numbers of graphics and interactive pages visited and video clips seen. When viewing the tapes, the observers made notes of a general style of the participants' progression through the module, indicating the tendency to follow a linear, orderly path through the module as a "sequentiality" score of 0, 1 or 2. Not surprisingly, three out of four participants with the least predictable, most nonlinear style of browsing style (given the score of 0) turned out to be Global learners.

Analysis of Verbalizations

The participants generated 885 verbalizations classified as Content, 262 verbalizations classified as Usability (55 of which were negative, and 143 of which were positive) and 106 classified as Confusion (64 of which were caused by navigational problems). Usability comments were analyzed and, combined with the summary of the focus group were used to make improvements in the module. Figure 1 shows distributions of the verbalizations in each of these categories across the participants. Participants 1 to 5 on the left of the graph are Mechanical Engineering students, new to the module, and the remaining participants on the right of the graph are Electrical Engineering students, already familiar with the module. Participants # 7 and # 8 are missing as the voice levels of their sessions too low.

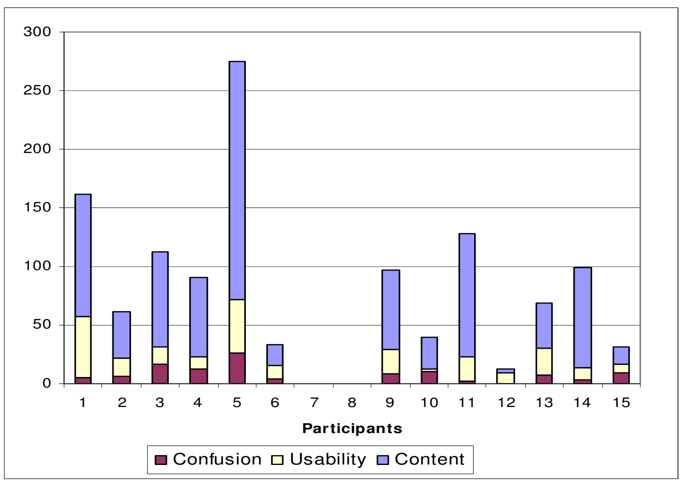

Figure 1: Distribution of Verbalizations among Participants Part 1

Content verbalizations were next broken down into 281 verbalizations referring to navigation (labeled Navigation in Figure 2 and including Navigation1 and Navigation2 sub-categories), 407 verbalizations referring to screens with mostly text and formulae (labeled Text in Figure 2 and including Text1 and Text2 sub-categories), and 191 verbalizations referring to screens that contained graphics, video or interactive components (labeled Mixed Media in Figure 2 and including Mix1 and Mix2 sub-categories).

Figure 3 shows distributions across the participants of the verbalizations in two categories labeled as Evidence of Lower Level Reasoning and Evidence of Higher Level Reasoning categories. The former category referred to simple cognitive tasks like stating actions, naming, reading out text, paraphrasing, etc., while the latter category referred to more complex cognitive tasks like strategizing, inferring, drawing conclusions, making connections, etc. The breakdown of the totals in these two categories, excluding Confusion and Usability verbalizations, is shown in Table 2. While there is a significant variance in the quantity of verbalizations among the participants, all three figures suggest that the Mechanical Engineering students (participants 1 to

5) generated more verbalizations in all categories than Electrical Engineering students did. Unfortunately, it is impossible to conclude whether that was because they all belonged to the AM group, or because the novelty factor was at play.

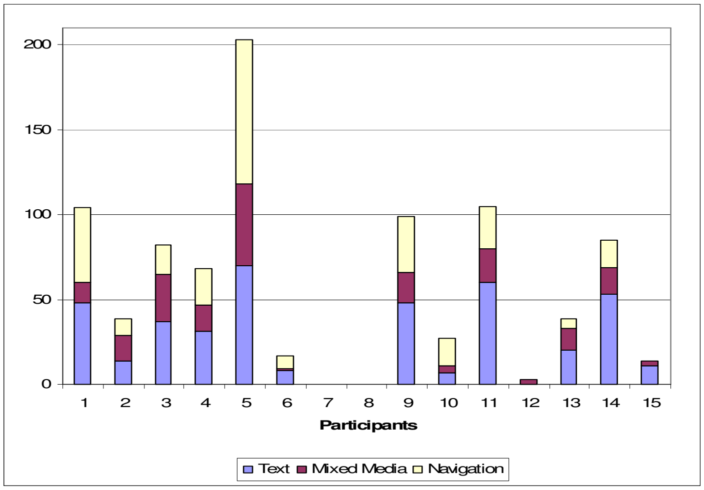

Figure 2: Distribution of Verbalizations among Participants Part 2

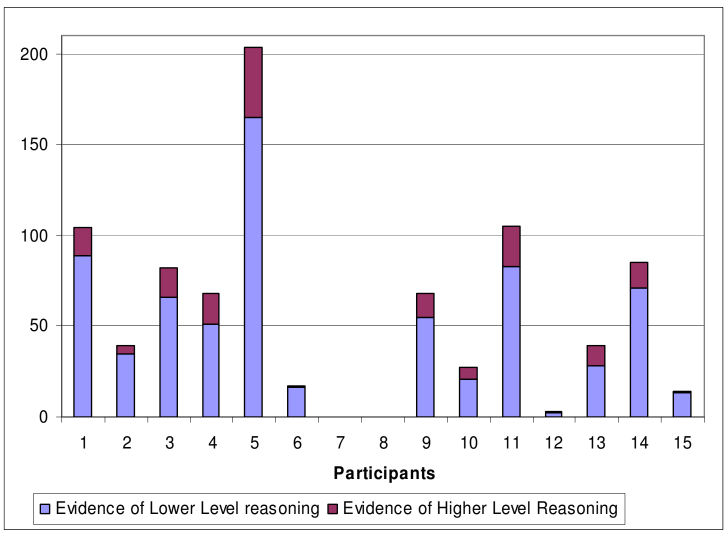

Figure 3: Distribution of Verbalizations: Lower vs. Higher Cognitive Level Reasoning

Table 2: Total Verbalization Count (Excluding Confusion and Usability)

	Lower Cogn. Level	Higher Cogn. Level	Total
Navigation	241	40	281
Text	339	68	407
Mix	135	62	197
Total	715	170	885

As Figure 3 and Table 2 show, all participants generated overwhelmingly more verbalizations in the lower cognitive category. This observation is consistent with the previously published results of the study[14] where the participants' pre-test and post-test scores were compared, and greater gains were found at lower cognitive levels of Bloom's Taxonomy. It is also consistent with the results of another study at the University of Texas[17], where the students were using the Talk-Aloud-Protocol working with a CD-ROM supplementing a course in Thermodynamics, and "the comments that were made consisted largely of a reiteration of the content on the screen, either through reading the text out loud, or describing or summarizing the text, narration, a graph, or interactive element." [17] In both the University of Texas and in the current study the students interacting with the multimedia modules were exhibiting mostly lower cognitive skills.

The students' GPA scores and Control Systems grades were positively correlated with the number of verbalizations in all categories, with the latter reaching statistical significance in several. Significant Pearson's correlation factors are shown in Table 3.

Table 3: Correlations between Grades and Number of verbalizations, n = 13

Verbalization category	Pearson's r
Text1	r = 0.628*, p = 0.022
Mix1	r = 0.616*, p = 0.025
Total Lower Cognitive Level	r = 0.6589*, p = 0.034
Text2	r = 0.742**, p = 0.004
Total Higher Cognitive Level	r = 0.654*, p = 0.015
Total Text	r = 0.665*, p = 0.013
Total Mix	r = 0.564*, p = 0.045
Usability	r = 0.764*, p = 0.002
All Verbalizations	r = 0.557*, p = 0.048

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

The correlations are particularly strong in Text2 and Usability categories, the former attesting to higher developed cognitive skills of the higher-achieving students (since analytical parts of the module, including derivations and formulae were classified as Text2 category), and the latter also to their better developed ability to communicate clearly and to follow the protocol of the experiment, requiring them to elucidate all their thoughts and actions. This observation is consistent with the positive correlations found between grades and time spent reviewing the module, as opposed to the quiz.

Conclusions and Recommendations

The authors identified two areas of interest in their investigation of the volunteers' interactions with the module – looking at verbalization patterns at different cognitive levels and looking at access and verbalization patterns among learners with different learning styles. The analysis of verbalization patterns at different cognitive levels revealed that the participants generated significantly fewer verbalizations indicative of the higher level cognitive processes as compared with the number of verbalizations at the lower level. It points to a pattern of superficial interactions with the module resulting in students benefiting more at the lower cognitive level. Such a conclusion is consistent with the previously reported quantitative analysis of the study[14] where the authors found greater achievement gains at the lower cognitive levels of Bloom's Taxonomy (Comprehension or Application), and smaller gains at the higher levels of Bloom's Taxonomy (Analysis and Evaluation). The observation of students' greater cognitive activity and learning gains at the lower levels of Bloom's Taxonomy is also consistent with the literature[17]. The number and depth of verbalizations on both cognitive levels were strongly correlated with the student grades. The authors see the observation of low cognitive activity accompanying interactions with the learning object as an indication of a need for further investigations of an important question of how to encourage, and effectively support, students' deep level learning and effective problem-solving, as opposed to a superficial understanding of the domain knowledge.

The analysis results of access and verbalization patterns among learners with different learning styles were somewhat disappointing. Six out of eight Electrical Engineering students seemed to have opted for a "strategic" approach and spent most of their time reviewing the quiz section of the module in order to prepare for the post-test, rather than exploring the module. Unfortunately this strategy made any conclusions on the correlations between their learning styles and their access patterns less reliable, thus reducing the observed pool of students who did explore the module in depth to only seven. Nevertheless, the observed navigation patterns were aligned with the students' recorded learning styles and differences in the way they accessed the module were also consistent with their differing learning styles. In particular, the differences in the way Sequential and Global learners accessed the material, and the correlations between the Sensing modality score and the number of interactive screens are aligned with the theoretical model.

Regarding the AM-BM group differences, the observations seemed to support the authors' hypothesis that the AM students would be more curiosity-driven and would generate more, and more complex, verbalizations. However, the biasing factor was that the observed differences could have been an artifact of a greater engagement with the module experienced by the students who had never seen it before. In hindsight, the authors' decision to include volunteers from a population previously exposed to the module (i.e. Electrical Engineering students) limited the conclusions that can be reliably drawn comparing these two groups. It is thus the authors' resolve to repeat the entire experiment with a new group of volunteers, entirely unfamiliar with the content of the module, so that this specific hypothesis can be properly tested.

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