2006-214: THE GROWTH OF TEXT LITERACY IN ENGINEERING UNDERGRADUATES

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The Growth of Text Literacy in Engineering Undergraduates

Abstract

The reading behaviors of experts in areas like physics have shown that experts in science domains are very active while reading—i.e., drawing from background knowledge, applying comprehension strategies, and responding to the author. Relatedly, the Perry model, which depicts students' epistemic orientations—i.e., how they value and respond to knowledge—indicates that freshmen are typically dualists, expecting information to be either true or false, but by their senior years, students recognize the relativism in knowledge, and the role of discourse in establishing consensus. Two questions were researched in this study, using a questionnaire methodology: i) Do engineering students become more active and metacognitive readers between their freshman and senior years; ii) do engineering students become less "transmission" oriented and more "transaction" oriented in their beliefs about text? The results are considered in terms of their consistency with other available data about engineering students' study behaviors, and in terms of implications for the design of undergraduate engineering curricula.

Introduction

The claim that "Engineering is a profoundly creative process"[1] seems entirely correct as a description of the nature of professional engineering. It also conveys a sense of the mindset and skill levels that are set as goals for advanced students in engineering through the ABET standards. How does a student become a reflective thinker and effective problem solver? This paper considers the role that text literacy may play in advancing engineering students toward the goal of making them reflective and creative problem-solvers.

A bit of skepticism may surround the idea that effective reading has much to do with engineering. Indeed, some educators have suggested that course textbooks provide no more than supplemental information and can be disposed of. To a large degree, associating scientific literacy with the passive deciphering of the words in a science textbook takes too narrow a view of the concept [2]. Rather, scientific literacy in a fundamental sense encompasses all the basic abilities of skilled reading, but also includes applying higher-order skills, like distinguishing between a hypothesis and a conjecture, data and evidence, and speculations and conclusions. Scientific literacy allows the person to capture an author's intended meaning, but also to go beyond it.

The present paper considers how engineering students may develop text literacy in two specific ways, which are operationalized in detail later. One is in their ability to become more cognitively engaged when processing text. The second way is by taking a "critical" (i.e., analytic) stance toward the author and material. Although text comprehension and the concept of literacy are well-researched and well-defined outside of engineering, this is the first attempt to consider these issues in the engineering domain.

Scientific Literacy and Development

Reading comprehension is an active process through which meaning is constructed. Often it demands that the reader take an active role to figure out the meaning of an unknown word, identify the major theme in the text, or use bridging inferences to maintain text coherence.[3] Current understanding of skilled reading has been shaped significantly by research on what expert readers do [4, 5, 6]. These studies demonstrated that successful comprehension depends on directed cognitive effort that is used to regulate and enhance learning from text. Skilled readers apply multiple reading strategies, termed metacognitive strategies, in a purposeful manner. These include setting reading goals, varying reading style according to the relevance of the text to reading goals, jumping forward and backward in the text to find information relevant to reading goals, making predictions about what the author will say, paraphrasing, explaining, and interpreting the text, and constructing summaries and conclusions. Skilled readers know multiple strategies and also know when to apply them [7, 8]. Norris and Phillips[2] define these and related skills as fundamental to literacy in science domains.

Text literacy is not an end in itself, but rather, a set of skills that provide the means to an end, viz., that of growing into the kind of knowledge and practices associated with scientific discourse and practice [2]. A basic transition that takes place across the undergraduate years relates to the ways that students view and value knowledge—more formally, to their epistemological knowledge. The Perry model, which depicts students' epistemic orientations—i.e., how they value and respond to knowledge—indicates that freshmen are typically dualists, expecting information to be either true or false. But by their senior years, students ought to recognize the relativism in knowledge, the possibility of multiple interpretations, the role of evidence, and the use of discourse in establishing consensus [9]. Pavelich and Moore[9] and others have shown that students develop intellectually, as evidenced by more sophisticated epistemological knowledge, during their college years.

Research Questions

Two fundamental kinds of knowledge related to text literacy may develop in engineering students across the undergraduate years – metacognitive skills related to text comprehension and epistemological views of the nature of knowledge. Two questions were researched in this study: i) Do engineering students become more active and metacognitive readers between their freshman and senior years; ii) do engineering students become less oriented toward true and correct facts (a "transmission" orientation) and more oriented to multiple defensible positions (a "transaction" orientation) in their beliefs about text and how it communicates? The first question addresses growth with respect to fundamental literacy skills. The second question addresses growth in students' orientations toward the knowledge communicated through text.

Questionnaire Study

Participants

One hundred forty-six students at a large university in the southwestern region of the United States participated in this study. Participants were recruited through engineering courses, as described later, and they volunteered to participate, without coercion. The experimenter did not provide compensation for participation. Two groups of participants were formed using a median split, based on self-reported completed college credits. Seventy-three participants had completed 61 or fewer college credit hours (Mean = 31.15, standard deviation [SD] = 21.42), and an equal number had completed more than 61 credits (Mean = 101.56, SD = 35.61). For the sake of convenience, the former group will be referred to as the Freshman-Sophomore group, and the latter as the Junior-Senior group, in the remainder of this paper. By chance, there were an equal number of males (65) and females (8) in both groups. The mean age of the Freshman-Sophomore group was 20.00 (SD = 3.40), and that of the Junior-Senior group 22.80 (SD = 4.04). Table 1 presents the distribution of majors for the two groups.

Table 1. Distribution of Majors by Level

Major	**Frequencies**	
	Freshman/Sophomore	Junior/Senior
Chemical Engineering	0	1
Civil Engineering	1	1
Computer Engineering	1	0
Computer Science	5	1
Electrical Engineering	5	4
Engineering Physics	1	2
Engineering Undecided	6	1
Industrial Engineering	7	3
Mechanical Engineering	20	11
Mechanical Technology	1	0
Petroleum Engineering	26	49
TOTAL	73	73

Note. The Freshman/Sophomore group are those students who completed 61 or fewer credit hours, and the Junior/Senior group were students who completed more than 61 credits.

Materials and Procedure

The materials included the Metacognitive Reading Strategies Questionnaire (MRSQ)[10, 11], which measures students' use of metacognitive comprehension strategies, and the Reader Belief Inventory (RBI) [12], which measures students' beliefs about text. Each instrument consisted of two subtypes of questions. The MRSQ taps cognitively-based analytic strategies and action-based pragmatic strategies. The two kinds of comprehension strategies are relatively independent [11], and are related to different levels of academic performance [10, 11]. The RBI consists of statements reflecting transaction and transmission beliefs about reading. Transaction beliefs emphasize the construction of knowledge by individual readers, whereas transmission beliefs regard text as a means of direct communication between author and reader, without interpretation [12]. The questions for each instrument are listed in the Appendix.

In order to recruit participants, the researcher visited engineering classes, with the prior permission of the instructor, and informed the students that he was interested in learning more about how engineering students processed text materials. Students who were willing to participate in the study submitted an e-mail address to the experimenter and were provided with the two questionnaires, as well as several demographic questions, via e-mail by the experimenter, within one day of indicating their interest in participating. Questions within each instrument were presented in a different random order for each participant, and the order of the instruments was counterbalanced across participants. Demographic questions always appeared at the end of the survey.

Results

Data from the two instruments were analyzed separately with level (Freshman-Sophomore vs Junior-Senior) as the primary factor, based on completed college credits, and instrument subtypes as the second factor. In the initial analysis, a mean score was computed for each participant for each instrument subtype. The means for the MRSQ are presented in Table 2.

Table 2. Mean Ratings for MRSQ by Level (Standard Deviations are in parentheses)

Strategy Type	Freshman/Sophomore	Junior/Senior	Mean
Analytic	3.430 (.553)	3.523 (.447)	3.476 (.503)
Pragmatic	2.886 (.691)	3.192 (.745)	3.039 (.732)
Mean	3.158	3.358	

Note. The rating scale for the MRSQ was as follows: *I use this strategy*
1: Never, 2: Rarely, 3: Sometimes, 4: Often, 5: Always.

An analysis of variance using the two academic levels (Freshman-Sophomore, Junior-Senior) and the two subtypes (Analytic, Pragmatic) of the MRSQ showed a main effect for level [F (1, 144) = 6.28, $p < .02$] and for strategy subtype [F (1, 144) = 45.68, $p < .001$]; the interaction of the two factors was not significant [F (1, 144) = 2.70, *ns*]. Two conclusions follow. The first was a highly significant difference in use of analytic over pragmatic strategies. The second was an increase in analytic strategy use and pragmatic strategy use from the freshman-sophomore years to the junior-senior years. The effect size for analytic strategy use across the two levels was .18, based on an estimate of the pooled variance for the two levels. For pragmatic strategy use, the effect size was .42. These effect sizes are quite modest, considering that the data span the students' undergraduate careers.

Another analysis of variance was conducted using the two academic levels (Freshman-Sophomore, Junior-Senior) and the two subtypes (Transaction, Transmission) of the RBI. The main effect for level was not significant [F (1, 144) = 0.20, *ns*]. The main effect for subtype was significant [F (1, 144) = 15.51, $p < .001$], as was the interaction of the two factors [F (1, 144) = 5.14, $p < .03$]. One conclusion that follows is that students significantly preferred a transaction orientation over a transmission orientation to text. This overall preference was modulated, though, by the interaction, which signals that mean agreement with transaction statements *decreased* as students progressed through the college years, while mean agreement with transmission statements *increased*, as shown by the means in Table 3. This is not the pattern we would expect, if students were progressing according to the Perry model [9]; according to the Perry model, we would expect the converse pattern. The effect size for transaction was .34, and for transmission it was .23.

Table 3. Mean Responses for RBI by Level (Standard Deviations are in parentheses)

Statement Type	Freshman/Sophomore	Junior/Senior	Mean
Transaction	3.502 (.508)	3.315 (.574)	3.409 (.548)
Transmission	3.062 (.600)	3.196 (.551)	3.129 (.578)
Mean	3.282	3.256	

Note. The rating scale for the RBI was as follows: *My response to this statement:* (1) Strongly Disagree, (2) Disagree, (3) Neutral, (4) Agree, (5) Strongly Agree.

An examination of the means for individual statements in the Appendix showed that 12 of the 16 analytic strategies and five of the six pragmatic strategies increased from the freshman-sophomore level to the junior-senior level. This pattern of gains is consistent with the statistical main effects reported earlier. Four of the six transaction strategies showed a decrease, and five of the six transmission statements showed an increase. This pattern is consistent with the statistical interaction reported earlier.

In order to examine which strategies in the MRSQ and statements in the RBI produced the largest effects, and thus to get a better sense of how students developed across this age span, independent t-tests were calculated for each questionnaire item. *P*-values for associated *t*-tests less than 0.05 were considered significant; those greater than or equal to 0.05 but less than 0.10 were considered marginally significant. (No statistical adjustment was made for the number of *t*-tests; however, interested individuals could implement such adjustments using the actual *p*-values in the Appendix within a Bonferroni [13] or similar method.) The results are summarized in the Appendix. In terms of strategies associated with overt actions, upper-level students differed significantly from lower-level students in terms of underlining and highlighting of text, annotating the text, and, marginally significantly, in terms of note taking. Regarding more cognitively oriented strategies, upper-level students compared to lower-level students differed significantly in terms of distinguishing between old and new text information, visualizing text descriptions, and searching out information relevant to specific reading goals; and marginally significantly in terms of evaluating whether the text contributed to reading goals, evaluating whether the text contributed to knowledge of the subject, anticipating how the text would be used, and inferring information that was not directly stated. In all cases, upper-level students exceeded lower-level students in the use of these strategies, except for visualizing text descriptions and inferring unstated information—there was a decrease in use of these latter strategies across the college career.

Regarding a transaction orientation to text, there was a significant decrease in liking to live through experiences described in text, and a marginally significant decrease in liking when people can disagree in their interpretations of a text. In terms of transmission strategies, there was a significant increase in focusing on what the author says.

Discussion

The analyses showed two major effects that address the questions posed in this study. Regarding the first question, there was a significant increase in the use of metacognitive reading strategies from freshman-sophomore to junior-senior years. This increase is consistent with the research literature on reading comprehension because use of these strategies is known to increase text comprehension and is thus generally adaptive in terms of academic performance [10]. Further, expository texts—the explanatory texts of science—are difficult for students [14]. This is because expository texts employ text (i.e., rhetorical) structures that differ from the kinds of text structures familiar to students (i.e., narrative structures). Expository text includes mathematical language, and refers to constructs that are unfamiliar to the reader. Based on the difficulty of expository text, as determined by reading researchers, it makes sense that engineering students would show some measure of growth in their reading skills as they face and master the challenges of expository text over the course of their undergraduate training, as shown in the data here.

Regarding the second question, students became less transaction oriented and more transmission oriented across their freshman-sophomore to junior-senior years. This decline is inconsistent with the Perry model for epistemic development during the undergraduate years, but it fits other findings [9] that indicated the difficulty in breaking students out of a transmission-of-knowledge mindset.

The implications of these findings cannot be fully appreciated without additional benchmarks that would allow better interpretation of the mean ratings for the MRSQ and RBI scales. Specifically, what is "high" and what "low" relative to some reference group? Thus, the remaining speculations are presented with a cautionary note to the reader.

Significantly higher scores for analytic strategies compared to pragmatic strategies, in the MRSQ, was a noteworthy outcome because it signals that engineering students engage more frequently in cognitively-oriented comprehension practices than the more pragmatic orienting and markup strategies, like underlining. Nevertheless, the overall mean for analytic strategies was a rather tepid value between "Sometimes" and "Often," suggesting more room for these students to develop. Further, as already pointed out, students did show growth over the course of their undergraduate experience in the use of these strategies. However, two additional observations need to be considered in interpreting that effect. First, the amount of growth was quite modest, considering the effect sizes. Second, the effect size for growth in pragmatic strategy use was more than twice as great as analytic strategy use. This difference is important because reading research has shown that pragmatic strategies may be helpful in remembering information, however, they may not be associated with deep comprehension processes. Nist and Holschuh [15] suggested that strategies like highlighting and underlining—strategies that fit the pragmatic-behavioral component—may provide a beginning point for learning deeper, more demanding strategies. Thus these strategies may be reflective of less-sophisticated readers who are developing toward the use of more analytic strategies and deeper comprehension of text materials. A closer look at the increase in analytic strategies further supports a view of an unsophisticated reader. Specifically, two analytic strategies that would signal deep comprehension processing—i.e., visualizing text descriptions and inferring information not presented in the text—showed a significant *decline* across the undergraduate years. Thus, the overall pattern of findings suggests that these students begin as weak readers, and over the course of their undergraduate experience increase their use of the most rudimentary comprehension strategies. In fairness to the students, it is important to bear in mind that the expository texts of science are difficult to process relative to more familiar narrative (story) texts [14]. Thus, the point here is not to judge students for their lack of facility with this difficult text form, but rather to point out a possible need to put more emphasis on these texts in the engineering curriculum, and to provide students with the learning aids and supports necessary to reach the level of facility with these texts expressed by skilled readers in science domains [4, 6].

Other research that my colleagues and I have conducted involving engineering majors fits the suggestion here that these students may be developing rudimentary, but not deep, comprehension strategies. Our research has shown that engineering students devote much time to solving assigned problems from the textbook, but much less time reading the textbook per se [16]. That research showed that a primary source of domain knowledge was from class lectures, not from the textbook. Other research that tracked engineering students as they worked through a CD-ROM on thermodynamics, as well as think-aloud data created when students were asked to verbalize what they were thinking as they read instructional texts in thermodynamics, suggested that these students did not express a rich repertoire of sophisticated reading strategy use [17, 18]. A common response in the think-aloud data was to provide verbatim or close paraphrases of the screen texts. Those findings are consistent with the present findings in suggesting that text processing is not an important component of engineering students' academic experience. Finally, the analytic strategies that showed significant growth across the college years in the present study are also the kind that would be useful to a student with very practical interests in completing homework sets—i.e., anticipating how knowledge gained from the text would be used, distinguishing between old and new text information, searching out information relevant to specific reading goals, and evaluating whether the text contributed to the goals. Strategies related to a deeper grasp of the material did not show significant growth over time—i.e., strategies like activating and revising background knowledge, revising questions about the text that were generated before reading the text, and considering alternate interpretations of the text.

Regarding students' decline in a transaction orientation to knowledge and increase in transmission orientation, a curriculum based on textbook problem sets and closed-form problems may encourage a growing dependence on factual information from the author. Ironically, it may discourage students from developing the kinds of orientations to knowledge (e.g. Perry Level 5: Contextual Relativism) [9] that are necessary for their professional work. Educators report that many engineering freshman believe that all problems have known solutions [9]. Ultimately, their professions will require them to reason and make decisions about problems in ambiguous situations; however, their undergraduate training may limit their ability to develop those skills. Pavelich and Moore [9] found that only one-quarter of seniors graduating from a project-based engineering program, with extensive experiential learning components, reached a level of epistemological knowledge sufficient for the demands of real-world problem solving (Perry's Level 5). Thus it appears difficult to advance students' orientations toward knowledge, under the best circumstances. Related to the introductory comment, it also follows that it is difficult to advance them to the developmental point of viewing engineering as a "profoundly creative process [1].

A possible counterargument here may be that engineering is based on facts, and on reconstructing the message intended by the author, in engineering texts. Thus the transmission model is the correct model for text comprehension. Although credible, this position has its limits, particularly as students advance in their training. Norris and Phillips [2] view reading scientific texts as a constructive process, using the example of a wave function, which they point out requires inferential processes on the part of the reader – a description of a wave function cannot not be written in such a way as to guarantee one and only one interpretation. At issue is not whether the facts of engineering are to be accepted and learned, but whether the student will go beyond the facts to consider the implications of the knowledge, asking how the knowledge could be applied, and so on. Scientific literacy comprises facility with the "interpretive strategies"[2] necessary for negotiating science texts. It also involves an understanding and appreciation of the social and political impact of science, and the need to consider multiple perspectives in sound scientific decision making [9].

Conclusions

The present findings indicate a need to look more carefully at undergraduate engineering curricula and to consider how those curricula may affect the development of comprehension strategies and orientations toward knowledge. A curriculum based on lectures, text, and other reference materials, and focused on solving paper-and-pencil problems may promote the development of comprehension strategies and skills, but they may be of the most rudimentary sort. These rudimentary strategies, involving underlining and highlighting the text, and making notes in the margins, may be helpful in completing homework sets and passing course tests. However, analytic strategies, like visualizing text descriptions, and inferring information that is not directly stated, are precisely the kinds of strategies one would find important in design and solving real-world problems. Thus, comprehension strategy development at the undergraduate level may not be sufficiently oriented toward the professional demands of these students after graduation.

The data here suggest that traditional engineering curricula may be a hindrance inasmuch as solving problems from a textbook, as opposed to emphasizing design and real-world problems [9] might evoke and promote a transmission-of-knowledge mindset. Current approaches to training engineers may not place students in learning contexts that advance their conceptions of knowledge, their use of reasoned discourse and of evidence and argument, and striving for consensus, which are typical of the norms and practice of science and engineering in the lab and workplace.

Limitations

The design and conduct of the present study are subject to several methodological limitations, which the reader should bear in mind when considering the conclusions. A major limitation is that the data were drawn from engineering students at a single institution. This places a potential limitation on the reliability and ability to generalize the findings. We are currently collecting a data set at another university, which will allow a test of the robustness of the reported results.

Readers should also note that the present study uses a cross-sectional design, not a longitudinal one. The latter would be more effective in measuring individual change across the undergraduate experience. The present results reflect differences in cohorts of students at different points in their undergraduate preparation; however, there is no guarantee that these student cohorts are comparable in basic academic and motivational respects.

A final limitation to the conclusions drawn from present study is that they are based on questionnaire data. It is possible that engineering students apply pragmatic comprehension strategies when processing texts, and express transmission beliefs with respect to texts, but implement analytic strategies and transaction beliefs in design and problem-solving contexts. This is a possibility that needs to be explored through additional data collection in academic settings that involve design and applied problem solving.

These limitations can be addressed in subsequent studies. The success of the current studies, the provocative nature of the results, and the potential implications for adjusting the engineering curriculum in ways that will better develop engineering literacy, warrant additional research in this area.

Appendix

Mean Ratings		Difference	*p*-value	Metacognitive Reading Strategies Questionnaire (MRSQ)
Freshman-Sophomore	Junior-Senior			**Analytic Reading Strategies**
3.56	3.85	-.288	.064	1. As I am reading, I evaluate the text to determine whether it contributes to my knowledge/understanding of the subject.
3.29	3.58	-.288	.060	2. After I have read a text, I anticipate how I will use the knowledge that I have gained from reading the text.
3.95	3.96	-.014		3. I try to draw on my knowledge of the topic to help me understand what I am reading.
3.22	3.41	-.192		4. While I am reading, I reconsider and revise my

				background knowledge about the topic, based on the text's content.
3.04	3.05	-.014		5. While I am reading, I reconsider and revise my prior questions about the topic, based on the text's content.
3.26	3.00	.260		6. After I read the text, I consider other possible interpretations to determine whether I understood the text.
3.60	4.03	-.425	**.004**	7. As I am reading, I distinguish between information that I already know and new information.
3.86	3.62	.247	.084	8. When information critical to my understanding of the text is not directly stated, I try to infer that information from the text.
3.19	3.53	-.342	.072	9. I evaluate whether what I am reading is relevant to my reading goals.
2.97	3.44	-.466	**.016**	10. I search out information relevant to my reading goals.
3.26	3.26	.000		11. I anticipate information that will be presented later in the text.
3.89	3.96	-.068		12. While I am reading, I try to determine the meaning of unknown words that seem critical to the meaning of the text.
2.78	2.81	-.027		13. As I read along, I check whether I had anticipated the current information.
3.49	3.64	-.151		14. While reading, I exploit my personal strengths in order to better understand the text. If I am a good reader, I focus on the text; if I am good with figures and diagrams, I focus on that information.
4.18	3.82	.356	**.008**	15. While reading I visualize descriptions to better understand the text.
3.33	3.41	-.082		16. I note how hard or easy a text is to read.
				Pragmatic Reading Strategies
2.68	3.04	-.356	.051	17. I make notes when reading in order to remember the information.
2.59	3.15	-.562	**.009**	18. While reading, I underline and highlight important information in order to find it more easily later on.
2.00	2.41	-.411	**.020**	19. While reading, I write questions and notes in the margin in order to better understand the text.
2.33	2.86	-.534	**.004**	20. I try to underline when reading in order to remember the information.
3.53	3.47	.068		21. I read material more than once in order to remember the information.
4.18	4.22	-.041		22. When I am having difficulty comprehending a text, I re-read the text.
				Reader Belief Inventory (RBI)
				Transaction Statements
3.81	3.51	.301	.072	23. I like the fact that two people can read the same book and disagree about what it means.
2.73	2.75	-.027		24. I often have strong emotional responses to what I read.
3.74	3.25	.493	**.001**	25. When I read, I like to imagine I am living through the experience too.
3.70	3.56	.137		26. I enjoy interpreting what I read in a personal way.

3.73	3.78	-.055		27. Reading for pleasure is the best kind of reading.
3.32	3.04	.274		28. I enjoy sharing the thoughts and reactions of characters in a book with others.
				Transmission Statements
2.92	3.18	-.260		29. The main purpose of reading is to understand what the author says.
3.27	3.40	-.123		30. When I read, I try to carry away exactly what the author meant.
2.30	2.37	-.068		31. People should agree on what a book means.
3.77	3.74	.027		32. I like books where you know exactly what the author means.
3.45	3.74	-.288	**.031**	33. When I read, I focus on what the author says is important.
2.66	2.75	-.096		34. Most books mean exactly what the say.

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