2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #39796

Analysis of Engineering Textbook Epistemologies

Dr. Michael Robinson, Saint Vincent College

Michael Robinson received his Ph.D. in Mechanical Engineering from Penn State University. He is currently an Assistant Professor of Engineering at Saint Vincent College in Latrobe, Pennsylvania. His academic experience includes positions as an Assistant Professor of Engineering at Messiah College, and as a Visiting Lecturer at Ashesi University in Ghana. His research interests include autonomous vehicle pedestrian avoidance algorithms as well as the development of threaded hands-on experiments to provide students with effective experiences of key engineering principles.

Analysis of Engineering Textbook Epistemologies

Abstract
Clarifying engineering epistemologies is a major aim for engineering education research. Much of the work to date has focused on philosophical considerations and determining students' epistemological development and beliefs; however, there is still room for clarification about what defines engineering thinking and knowledge and what distinguishes engineering epistemologies from related fields such as natural science and mathematics. This paper analyzes sections from several introductory electrical engineering textbooks spanning roughly 80 years of publication to determine what epistemological beliefs are present. Explicit epistemic statements are compared for consistency to the epistemology implied by text content. Attention is also given to how the content of these textbooks can be classified according to Whitehead's rhythm of education. It is found that the earliest texts emphasize theory, while modern texts all emphasize analysis. Verbal explanations are minimized over time in favor of worked examples and practice problems. Two texts analyzed emphasize applications and design, but these texts are not typically used as introductory texts in electrical engineering despite covering much of the same content as traditional engineering texts. Recent texts include more differentiation in material in terms of Whitehead's rhythm of education; however, material is still overwhelmingly confined to the precision stage.

Introduction
Engineering education has a history of recognizing the importance of philosophical considerations on educational research and practice [1]. This is reflected in a 2006 statement from a group of leading engineering educators titled *The Research Agenda for the New Discipline of Engineering Education* [2, p. 259] where "engineering epistemologies" is cited as one of five research directions. Epistemology is there defined as "research on what constitutes engineering thinking and knowledge within social contexts now and into the future." That broad definition is applied in "drastically different ways" as Beddoes [3] found by investigating diverse sources of engineering education scholarship since the 2006 agenda. Interest in epistemology within engineering education comes in part from its relation to students in three key areas: academic motivation, aligning student epistemology with competent engineering practice, and personal growth.

Students' epistemologies are a key factor in their motivation and academic success. For example, Faber and Benson [4] related students' epistemic beliefs to their performance on an open-ended biomedical-engineering problem. Students without epistemic goals (i.e., students with goals like finishing quickly and getting the question right) spent less time on the assignment and showed ineffective problem-solving strategies such as seizing on their first idea and freezing on that solution even when asked to review their work. Yang also found first-year students' epistemic beliefs correlated with academic success [5].

Understanding students' epistemic views is key for helping them develop a view of knowledge in line with that of practicing engineers. For example, Gainsburg [6] showed that practicing engineers often consider engineering judgement the ultimate criteria for design decisions and sometimes only use analysis to justify designs after the fact. That study suggests that giving students model-eliciting activities and opportunities for reflection, as well as instructors making their epistemology transparent, can help students make progress towards a mature view of epistemology.

Epistemology is important for the personal growth of engineering students. It is generally considered a mark of intellectual maturity to pursue the truth in different contexts. Smith et al. [7] investigated students' epistemic frames in a junior-level thermodynamics course and found that many students approach engineering knowledge in the context of a course as a memorization task, not because they think that is the best way to learn, but because they believe that it is a surer path to a satisfactory grade. Whether or not this approach is effective in any particular class, it is a missed opportunity for personal growth and may develop a habit of deferring to perceived authorities in place of making informed judgements. This in turn may have negative effects in areas such as social and ethical considerations of engineering design.

Although investigating student epistemology is important, there is still an open question about the kinds of epistemology prevalent in the engineering curriculum itself. It is challenging to capture in a coherent way the broad multidisciplinary field of engineering. Engineering knowledge has many elements including "innovation, critical thinking, systems thinking, biology, mathematics, physical sciences, engineering sciences, problem solving, design, analysis, judgment, and communication" which are referred to below as the 2006 agenda elements [2, p. 260]. As this list indicates, engineers must approach designs in diverse ways including theoretical principles, models, design codes, rules of thumb, judgement based on experience, trial and error, and perhaps at times even fortuitous guessing. These elements are not mutually exclusive; they often inform and confirm one another. At other times one element provides key knowledge lacking in other areas. At still other times the engineer must choose between conflicting accounts indicated by these ways of knowing. At a minimum these elements have significantly different epistemologies which lead to different ways of educating engineers.

The studies above explore an output of engineering education, that is, students and their epistemology; this study investigates an input of engineering education, that is, engineering textbooks. It asks what engineering textbooks have to say about engineering thinking and knowing and how epistemic content has changed over time. A general view of epistemology is adopted here like that of the 2006 research agenda [2]. Epistemology here refers to engineering ways of thinking and knowing and the relation of engineering knowledge to its elements described in the preceding paragraph. Three areas are investigated in each text: stated aims, explicit epistemic statements, and implicit epistemology as inferred from the relative prevalence of individual elements of engineering knowledge. Additionally, given the connection between epistemology and pedagogy, attention is also given to the presentation of knowledge by following Whitehead's model of the rhythm of education [8].

Whitehead's rhythm of education is a way of categorizing different stages in the process of education. Heywood [1] describes this model as a theory of motivation. Whitehead conceived all education as following three stages: romance, precision, and generalization. He believed these phases must be followed in both large and small cycles throughout an education. Romance is "the stage of first apprehension… romantic emotion is essentially the excitement consequent on the transition from bare facts to first realisations of the import of their unexplored relationships" [8, p. 28]. The student then advances to precision which "proceeds by forcing on the students' acceptance a given way of analysing the facts, bit by bit" [8, p. 29]. The final stage of generalization is "a return to romanticism with the added advantage of classified ideas and relevant technique" [8, p. 30]. The texts below are analyzed for the extent to which content follows a rhythm like that of Whitehead.

Overview of texts

Seven texts spanning almost 80 years of publication are analyzed to demonstrate epistemological continuity and change between authors and across time. The texts analyzed here are all chosen from a single engineering topic. This demonstrates how different authors at different times ostensibly approach the same task. Future studies may look at books across a curriculum, but this was thought to be a less effective approach for the present question. Introductory circuit analysis texts were selected because most engineering programs require an introductory circuit analysis course. To further narrow the scope of investigation, only the frontmatter and introductory content of each book is considered in depth, although the entire contents of the book were surveyed to approximately determine the relative prevalence of theory, analysis, design, and judgement. Several limitations of this approach must be acknowledged before continuing.

Since all these texts are introductory in nature, it would not be surprising if the epistemologies found in these books are at a lower level of advancement than later engineering studies. This paper is not directly concerned with classifying levels of epistemological advancement, but rather with noting similarities and differences within these texts. Student demographics also changed significantly over the period of publication of these books and authors may have adapted their content to the needs of current students. This study does not advance any opinion on what material is most essential for a first electrical circuit course except to the extent that such decisions reveal an explicit or implicit epistemology.

Five of the books analyzed here are intended for use in a first electrical circuit course in engineering programs. They are presented in chronological order. Following the authors names is a label used to reference each text for the remainder of this paper. These five books are *Electric Circuits* [9] by Members of the Staff of the Department of Electrical Engineering at the Massachusetts Institute of Technology (M.I.T. 1940); *Circuit Analysis* [10] by Elias M. Sabbagh (Sabbagh 1961); *Electric Circuits,* Second Edition [11] by James W. Nilsson (Nilsson 1983); the same book in its tenth edition [12] (Nilsson 2015); and *Fundamentals of Electric Circuits*, Sixth Edition [13] by Charles K. Alexander and Matthew N.O. Sadiku (Alexander 2017).

Two additional texts are referenced here even though they are not strictly intended for the same purpose. They are included to provide a different epistemic perspective. *The Art of Electronics,* Second Edition [14] by Paul Horowitz and Winfield Hill (Horowitz 1989) is not an introductory circuit text but is instead a sort of "crash course" in electronics design at the university level; nevertheless, its value is demonstrated by the fact that one of three editions has been in print for over forty years. *Principles of Electric Circuits,* Fifth Edition [15] by Thomas L. Floyd (Floyd 1997) covers much of the same material as the first five textbooks above, but the pacing and practical focus are likely more suitable for technical schools or engineering technology programs.

The following analysis considers the texts above in three groups. M.I.T. 1940 and Sabbagh 1961 are considered together as early engineering texts. Horowitz 1989 and Floyd 1997 are considered together because of their practical focus. Nilsson 2015 and Alexander 2017 are considered together as recent engineering texts. Nilsson 1983 is also included in this group to allow comparisons between editions of the same text.

Early engineering texts

The aims of M.I.T 1940 [9, p. v] are stated in the forward which describes how the electrical engineering department at M.I.T. revised their entire curriculum to bring about “a new synthesis of educational material … with a breadth of view not easily approached by an author working individually.” This synthesis is briefly presented in a 13-page long introduction which gives a history of the purposes, practical accomplishments, experimental results, and theoretical development of electrical engineering.

Explicit epistemological statements are common in M.I.T 1940. The introduction contains many statements establishing engineering epistemology as grounded in practical design needs, scientific experiments, and first principles. The authors [9, p. xxii] state that “The history of electrical engineering makes clear that the art is built on a set of underlying principles which in their essence are not many.” This fundamental knowledge allows engineers to approach their careers “not only as technological experts, but also researchers who undertake to supply new methods, ideas, and things” [9, p. xxxii]. Much effort is spent in M.I.T. 1940 justifying basic circuit theory approximations based on the more general electromagnetic theory. The authors [9, p. xxxiii] acknowledge that “Circuit theory is more readily grasped at first than is the basic field theory from which it is derived” but believe that electromagnetic theory “is necessary for the full understanding of electrical processes and phenomena.” Here engineering knowledge is presented as knowing how parts relate to a whole in a theoretical explanatory framework.

Surveying the contents of M.I.T. 1940 reveals an emphasis on written explanations which is uncommon for the texts analyzed here. There are many graphics and equations, but they are frequently separated by long sections of text. Practical material is limited on the whole, but occasional extended practical reflections can be found. This appears to be consistent with the authors’ aim.

The aims of Sabbagh 1961 [10, p. iv] are “to provide a firm foundation the student of electrical engineering. The student will be fully prepared to move progressively to more complex applications of principles.” As with M.I.T. 1940, presentation of basic principles is seen as the essential starting point.

Introductory material in Sabbagh 1961 makes many and varied explicit epistemic statements. It begins its preface with a review of the experimental and theoretical basis of electrical engineering. It summarizes the sources of engineering knowledge as follows [10, p. iii]: “The science of engineering is based on results obtained through experimentation. From these results theories are developed. By logical reasoning and application of the theories, new conclusions are forecast and other results are predicted.” Although following the same basic approach of M.I.T. 1940 in deriving circuit theory from electromagnetic theory (a path not followed by any other texts reviewed here) the necessity of this approach is reduced in Sabbagh [10, p. 3] who states that “A thorough understanding of electrical phenomena must be based upon a knowledge of electrical and magnetic fields, but it is not necessary to understand this theory completely in order to use circuit theory effectively.” This raises a key question for engineering epistemology: How much theoretical knowledge is needed to competently design systems? Engineers may have an imperfect theoretical knowledge of the systems they design, and yet they are able to successfully design solutions. When speaking of electric and magnetic fields, Sabbagh [10, p. iii] states that no one “has yet proved that these fields have a real physical existence… whether these fields do physically exist or not, the assumption of their presence gave a great impetus to the advancement of electrical engineering in all its branches.” It seems that engineers use theory to explain what happens, but these explanations are not as concerned with the fundamental nature of a thing as those pursued by the physicist. If physicists change their understanding of a phenomena, but the result is the same, engineers may not embrace this change. A simple example from electric circuits is the acceptance of the conventional direction of current flow from high to low electric potential, even though negative charge carriers travel in the opposite direction.

Surveying the contents of Sabbagh 1961 shows an emphasis on equations. Text often serves merely to link equations in a chain of derivation. This indicates a shift from the theoretical perspective of M.I.T. 1940 towards a focus on analysis, which is consistent with the explicit statements above as well as the book’s title (*Circuit Analysis*). Practical material is minimal, but the author never claims such instruction as an aim.

Turning to Whitehead’s stages of romance, precision, and generalization reveals a relatively undifferentiated presentation in these books. While both books begin with frontmatter of a breadth and even elegance uncharacteristic of later texts (which could be considered a stage of romance), the content of the books is almost exclusively in the precision stage. M.I.T. 1940 does present a significant amount of practical information about electrical components in Chapter 1, which could be considered generalization; however, this is not the general trend.

Practical engineering texts

The next group of texts enters a debate with early engineering texts about content and emphasis. This is primarily a pedagogical debate, but it has epistemic consequences. These practical texts present an epistemology that engineering knowledge takes its source and validity from engineering devices, and theory is one tool used in the development of such devices.

Horowitz 1989 [14, p. xix] presents its aims by explaining why electronics is more like an art than a science: “By ‘art’ we meant the kind of mastery that comes from intimate familiarity with real circuits, actual devices… rather than the more abstract approach often favored in textbooks on electronics.” The authors expand this concept by saying that “There is no path of learning that takes you, by logical steps, from neophyte to broadly competent designer.” Engineering knowledge is here distinguished from other branches of knowledge by its complexity and interconnected nature as was seen in the 2006 research agenda [2] above.

Many explicit epistemic statements justify the approach of Horowitz 1989 which deviates from the methods preferred in previous texts. The authors [14, p. xxi] believe that “Much of the favorite pedagogy of beginning textbooks is quite unnecessary and, in fact, is not used by practicing engineers." For this reason, they prefer a "largely nonmathematical" treatment because "Electronics, as currently practiced, is basically a simple art, a combination of some basic laws, rules of thumb, and a large bag of tricks." The authors [14, p. xix] do acknowledge a potential hazard of their "nuts and bolts approach… most notably a frighteningly quick obsolescence." Despite this warning, the major content of this book has endured for over 40 years having undergone only two new editions. Even though change is a defining feature of engineering knowledge, this book seems to demonstrate that the aim of bringing the reader "to the point of understanding clearly the choices one makes in designing a circuit" [14, p. xxi] has enduring value.

The contents of Horowitz 1989 emphasize text. This text serves primarily to develop understanding of practical considerations and tradeoffs in circuit design. Theory and analysis are relatively deemphasized. This implicit epistemology aligns with the explicit statements found above.

Floyd 1997 [15, p. vii] states its aim as providing "a comprehensive, practical coverage of basic electrical concepts and circuits … troubleshooting and applications are emphasized." Few direct epistemic statements can be found; yet, this text has a distinct implicit epistemic approach. Of the books considered here, this text is the only one that makes significant use of analogies and pictorial representations of circuits. Since unaided human senses in general cannot perceive electrical phenomena, analogies seem particularly helpful. There is a well-known analogy between electrical parameters and fluid motion in pipes. Voltage is a push that causes electrical current in the same way a pump or gravity causes fluid flow. This analogy has helped many learners form a mental image of circuit behavior, and yet it is almost completely absent from other texts, at least in the sections analyzed here where it would naturally fit. A student familiar with this fluid analogy may find its omission an indication that engineers do not think in this way. This would seem to be a regrettable epistemic conclusion. In addition to analogies, pictorial representations of circuits accompany traditional schematics as a way of grounding circuit concepts in the experience of students. For example, voltage sources and lamps are given their conventional schematic symbols but are shown alongside a drawing with a pictorial battery and light bulb. A student may also wonder why this approach is considered inappropriate for engineering undergraduate courses.

The content of Floyd 1997 emphasizes graphics as noted above, but equations and analysis are also prevalent. There is a clear emphasis on procedural knowledge which deviates from the judgement emphasis of Horowitz 1989. While pictures and practical information about troubleshooting clearly align with stated practical aims, the extensive emphasis on analysis may be seen as inconsistent with this aim. If analysis is seen as another kind of procedural knowledge this inconsistency is resolved. Although most engineering programs would not see engineering analysis as strictly procedural knowledge, there is not a significant difference in the presentation of analysis in Floyd 1997 and the recent engineering texts below.

These practical texts address Whitehead's stages of romance, precision, and generalization in more varied ways than the early engineering texts above. Horowitz 1989 often includes short "romantic" sections establishing ideas before proceeding to precision. For example, the beginning of the section presenting Ohm's law starts "This is a long and interesting story. It is the heart of electronics. Crudely speaking, the name of the game is to make and use gadgets that have interesting I-versus-V characteristics." Horowitz also seems to operate more frequently in the generalization stage, which aligns better with the activities involved in engineering design, and with Whitehead's [8, p. 41] conception of the role of a university. Floyd 1997 begins and ends each section with "tech tips" which could be considered "romantic" and "generalization" stages. At a minimum, these sections create something of a differentiated rhythm in the text that implies a bigger picture of engineering knowledge than that indicated by precision alone.

Recent Engineering Texts

The debate about the relative emphasis of theory, analysis, applications, and design continues with recent engineering texts. These texts represent a continuation of the shift from theory to analysis begun by Sabbagh 1961. Design and practical considerations are of secondary importance and often presented in the context of applying a particular theory.

Nilsson 2015 [12, p. xvii] states its aims as follows: "To build an understanding of concepts and ideas explicitly in terms of previous learning… to emphasize the relationship between conceptual understanding and problem-solving approaches" and "to provide students with a strong foundation of engineering practices." These aims are the most comprehensive of any of the texts reviewed and indicate an attempt to balance many of the elements from the 2006 agenda including theory, analysis, and design.

Explicit epistemology in Nilsson often focuses on the role of models in engineering knowledge. The preface of Nilsson 1983 [11, p. vii] states that engineering design "depends in part on the ability to construct mathematical models of electrical components." Nilsson 2015 [12, p. 6] includes a similar statement in the introduction with a slightly different emphasis: "An electric circuit is a mathematical model that approximates the behavior of an actual electrical system. As such, it provides an important foundation for learning – in your later courses and as a practicing engineer – the details of how to design and operate systems." This aligns with an epistemology of analysis preceding practice.

An epistemic shift can be detected between editions of Nilsson towards more certainty in engineering analysis. Nilsson 1983 [11, p. 5] states that "In circuit theory, *we regard* (emphasis mine) the separation of charge as creating an electrical force (voltage) and the motion of charge as creating an electrical fluid (current)." This seems like the statement in Sabbagh that the real existence of electrical properties is not essential for engineering knowledge. Nilsson 2015 [12, p. 11] includes almost the same sentence: "In circuit theory, the separation of charge creates an electrical force (voltage) and the motion of charge creates an electrical fluid (current)." Perhaps this change was for brevity or clarity, but it is epistemically significant. When discussing ideal resistors Nilsson 1983 begins by saying "One must keep in mind several important properties of the ideal resistor" and follows by describing three assumptions. Nilsson 2015 omits much of this discussion, presenting only one assumption and ends by saying "In this book we assume that the simplifying assumptions are valid." A similar statement is made earlier in Nilsson 2015 [12, p. 11]: "In this book, we use models that have been tested for between 20 and 100 years; you can assume that they are mature." While the same approach of assuming the validity of models is used in Nilsson 1983, the prevalence of such statements in the later edition does seem to communicate that engineering knowledge is established and that assumptions have already been verified.

The implicit epistemology of the Nilsson texts shows a significant change over time. The earlier edition emphasized text; the later edition emphasizes equations. The second edition does not have separate worked example problems in chapter 2; in the tenth edition roughly a third of the pages in chapter 2 are devoted to worked examples. The aims presented above seek to balance theory, analysis, and design, but the contents of the texts heavily emphasize analysis, especially in the later edition.

Alexander 2017 [13, p. xii] states their aim as "to present circuit analysis in a manner that is clearer, more interesting, and easier to understand than other circuit textbooks, and to assist the student in beginning to see the 'fun' in engineering." Later the authors [13, p. 4] state "Our objective in this book is not the study of various uses and application of circuits. Rather, our major concern is the analysis of circuits." While Alexander is more explicit in its focus on analysis, this text seems to include roughly the same amount of theory and design material as Nilsson 2015.

Few explicit epistemic statements were found in Alexander 2017. The relevance of theory is explained in Alexander [13, p. 4] as follows: "Circuit theory and electromagnetic theory are the two fundamental theories upon which all branches of electrical engineering are built." It goes on to say that basic circuit theory "is the most important course for an electrical engineering student, and always an excellent starting point for a beginning student in electrical engineering education." Here the debate with early engineering texts and practical texts over the starting point of electrical engineering knowledge is not presented; no acknowledgement is made that the authors are making a pedagogical decision with epistemic consequences. The word "understand" is used frequently throughout the text. Many learning objectives include the word "understand" as, for example when Alexander [13, p. 30] presents the objective for Ohm's law as follows: "Know and understand the voltage current relationship of resistors (Ohm's law)." This phrasing has significant epistemic consequences since knowing the equation for Ohm's law is different than understanding that equation; however, the following chapter does not clarify the difference. When presenting Ohm's law, Alexander 2017 [13, p. 31] notes in passing that Ohm's law was initially rejected by the scientific establishment of that day. From an epistemic perspective, it would have been interesting to say more here.

The contents of Alexander emphasize analysis, which clearly aligns with their aims. Text is minimal, which is described by the authors [13, p. xii] as a "student-friendly writing style" which "avoid(s) wordiness and giving too much detail that could hide concepts and impede overall understanding of the material." Alexander 2017 claims to include 2,481 problems of various kinds which sends a consistent message emphasizing analysis.

Modern engineering texts follow a structure which can be mapped to Whitehead's stages of romance, precision, and generalization, at least to some extent. Chapters begin with an application of the theory to be presented; applications are returned to after the main material of the chapter. While these "romantic" and "generalization" sections are brief and often vague, this pattern may represent a development over early engineering texts.

Before leaving modern texts, it is briefly noted that they all do something which is largely absent in older texts: they address the student directly in the context of their course. This is similar to a concept from the theatre where an actor may "break the fourth wall" which separates them from the audience by addressing the audience directly, or referring to the play as a play. Recent texts acknowledge the context of a student in a college class who may be potentially struggling with the material, disengaged, or doubtful about the relevance of their course to engineering practice. This paper does not advance an opinion about the suitability of this practice, but it does seem to have epistemic significance. Papers like [7] indicate that students may activate unhelpful epistemic frames within the context of a course and it is possible that reminding students they are in a course may strengthen this effect.

Summary of epistemic trends

This paper has analyzed seven introductory electrical circuits texts for their explicit and implicit epistemology. It is now possible to summarize important similarities as well as debates. All these texts present engineering knowledge as a combination of elements from the 2006 agenda with emphasis varying between theory (M.I.T. 1940), analysis (Sabbagh 1961, Floyd 1997 and Alexander 2017), and design (Horowitz 1989 and, to a lesser extent, Floyd 1997). A summary is shown in Table 1. While the Nilsson texts state an aim to balance these goals, the material presented indicates a strong preference for analysis which becomes more pronounced in the later edition. Since all these texts contain roughly 800 pages, emphasis in one area likely comes at the expense of other areas.

Title	Publication date	Content emphasis
Electric Circuits [9]	1940	Theory
Circuit Analysis [10]	1961	Analysis
Electric Circuits, Second Edition [11]	1983	Analysis
The Art of Electronics, Second Edition [14]	1989	Design
Principles of Electric Circuits, Fifth Edition [15]	1997	Analysis/ design
Electric Circuits, Tenth Edition [12]	2015	Analysis
Fundamentals of Electric Circuits, Sixth Edition [13]	2017	Analysis

Table 1: Book titles, publication date, and summary of content emphasis

Both early and modern engineering texts focus on abstractions, although they do so in significantly different ways. Early texts emphasize theory, while later texts emphasize analysis. Despite the natural connection between theory and analysis, the difference between early and modern engineering texts is to such an extent that their content could scarcely be recognized as belonging to the same course. This difference is not due to any change in technical understanding over time, but due to a shift at least in pedagogy which likely reflects a change in epistemology as well. Theory in early books is seen as demonstrations of how a few principles explain diverse results; analysis in modern books produces results that may or may not be connected in a student's mind to fundamental principles except perhaps through equations. These changes are likely motivated by many factors, not the least of which is educational exigencies created by changes in student demographics; nevertheless, later authors may explicitly disclaim the approach of earlier texts as seen above. These texts do indicate that the norm of abstraction before practice in engineering education has existed throughout the period analyzed here. This preferencing of abstraction is to such an extent that there appears to be something of a taboo in engineering texts on anything seeming too practical, like the design-based approach of Horowitz 1989, or informal, like analogies and pictorial circuits presented in Floyd 1997. Although many four-year engineering programs may consider the approach of Floyd to be unsuitable for their purposes, it cannot be denied that modern engineering texts have much more in common with Floyd than they do with early engineering texts.

Another key shift over time is away from explicit epistemic statements. Older texts did more to motivate their choice of emphasis while modern texts seem to approach such choices as inevitable. Early engineering texts and practical texts indicate more uncertainty and qualifications around the applicability of theory while modern texts minimize discussion which would create a sense of uncertainty. When modern texts present practical details, they are provided as applications of theory, not as raising doubts about the applicability of theory.

Recent texts offer more regular differentiation in material than older texts, which may better follow the model of Whitehead's rhythm of education. Brief applications are used to introduce topics (somewhat like the romantic stage) and apply material (roughly like generalization). Most of the text still operates in the precision stage, but the awareness of a need for differentiated modes of instruction is at least a promising trend. Of the texts considered here, only Horowitz 1989 spends a considerable percent of the content on generalization. It is likely that an applied approach is more congenial to this kind of presentation.

Statements throughout the 2006 research agenda seem to define engineering by its orientation towards the future and therefore this paper concludes with possible directions for epistemology in engineering texts. It is likely that practical exigencies will continue to drive much of textbook content; however, this is not likely to produce a coherent vision of engineering knowledge like that sought by the 2006 research agenda. Abstraction has conventionally been preferred over practical training in engineering education; however, the emphasis on analysis of recent books limits epistemic scope. This focus on analysis also tends to confine engineering education to the precision stage and limits opportunities for Whitehead's romantic and generalization stages. It is suggested that textbooks with a more equal balance of theory, analysis, design, and judgement would create a distinct and compelling engineering epistemology in the minds of students. Such balance is desirable even in introductory texts like those analyzed here, as communicating engineering as an engaging endeavor is key to student retention and motivation, especially at the beginning of students' academic careers.

References

[1] J. Heywood, "Philosophy, Engineering Education And The Curriculum.," in *2008 Annual Conference & Exposition*, Pittsburgh, PA, 2008.

[2] "The Research Agenda for the New Discipline of Engineering Education," *Journal of Engineering Education*, vol. 95, no. 4, pp. 259-261, 2006.

[3] K. D. Beddoes, "Undisciplined Epistemology: Conceptual Heterogeneity in a Field in the Making," in *122nd ASEE Annual Conference & Exposition*, Seattle, WA, 2015.

[4] C. Faber and L. C. Benson, "Engineering Students' Epistemic Cognition in the Context of Problem Solving," *Journal of Engineering Education,* vol. 106, no. 4, pp. 677-709, 2017.

[5] Y. Yang, "Examining Epistemological Views of Engineering among First-Year Engineering," in *126th Annual Conference and Exposition*, 2019.

[6] J. Gainsburg, "Engineering Students' Epistemological Views on Mathematical Methods in Engineering," *Journal of Engineering Education,* vol. 104, no. 2, pp. 139-166, 2015.

[7] C. Smith, A. Bowen, D. Montfort and M. Koretsky, "Identification of Students' Epistemological Frames in Engineering," in *121st ASEE Annual Conference & Exposition*, Indianapolis, IN, 2014.

[8] A. N. Whitehead, The aims of education and other essays, New York: Macmillan, 1929.

[9] M.I.T. Staff, Electric Circuits, The M.I.T. Press, 1940.

[10] E. M. Sabbagh, Circuit Analysis, Ronald Press Company, 1961.

[11] J. W. Nilsson, Electric Circuits, Second Edition, Addison-Wesley, 1983.

[12] J. W. a. R. S. A. Nilsson, Electric Circuits, Tenth Edition, Pearson, 2015.

[13] C. K. Alexander and M. N. Sadiku, Fundamentals of Electric Circuits, Sixth Edition, McGraw-Hill Education, 2017.

[14] P. Horowitz and W. Hill, The Art of Electronics, Second Edition, Cambridge University Press, 1989.

[15] T. L. Floyd, Principles of Electric Circuits, Fifth Edition, Simon & Schuster, 1997.