English for Specific Purposes 62 (2021) 46–57

Contents lists available at ScienceDirect

English for Specific Purposes

journal homepage: http://ees.elsevier.com/esp/default.asp

Development of component analysis to support a research-based curriculum for writing engineering research articles

Gerald Rau

Department of Electrical Engineering, National Chung Cheng University, No.168, Sec. 1, University Rd., Minhsiung, Chiayi, 621301, Taiwan

A R T I C L E I N F O

Article history:
Available online 25 December 2020

Keywords:
Genre analysis
Argument theory
Component analysis
Research article
Curriculum development
ELF

1. Introduction

Due to the increasing globalization of both technology and academic research, many engineering graduate students are required to publish research articles (RAs) in an indexed English-language journal before graduation. Although genre analysis has helped clarify the structure of individual sections of RAs, little research has looked at the structure of whole articles, particularly in engineering. Moreover, even textbooks whose titles include engineering may not distinguish between science and engineering formats for RAs (Silyn-Roberts, 2013) and books on technical writing often include only a few pages on research articles (Laplante, 2018). The lack of research and good teaching materials has forced many students to learn the expected format by trial and error, leading to frustration and delay, especially among those using English as a lingua franca (ELF).

Abbreviations: BAWE, British Academic Written English Corpus; BME, Biomedical Engineering; CARS, Creating a Research Space; CE, Chemical Engineering; CSIE, Computer Science and Information Engineering; EE, Electrical Engineering; ELF, English as a Lingua Franca; IMRaDC, Introduction, Materials and Methods, Results and Discussion, Conclusion; IMRD, Introduction, Materials and Methods, Results, Discussion; IPC, Introduction, Proof, Conclusion; IPTC, Introduction, Product or Process, Testing, Conclusion; ME, Mechanical Engineering; MOOC, Massive Open Online Course; RA, Research Article; TA, Teaching Assistant; ZPD, Zone of Proximal Development.

E-mail address: gerryrau@hotmail.com.

https://doi.org/10.1016/j.esp.2020.12.001

This paper reports the development of a research-based curriculum to help engineering graduate students write RAs in the format of their discipline, paying special attention to the needs of ELF learners. During development, attention to student feedback and learning outcomes were used to continuously improve the materials. The goals of this study were:

1) To develop a new technique, component analysis, to allow students to quickly, clearly, and accurately describe the typical structure(s) of engineering research articles in their subfield.
2) To develop a curriculum for engineering graduate students which will teach and assess their ability to analyze the structure of exemplar articles in their subfield and use that information to write their own research articles.
3) To develop supplemental resources to enhance success of ELF students in various learning situations: courses taught by writing instructors in a language center, by subject specialists in a department, or self-study.

Development of a research-based curriculum requires extensive time and effort, but any complex task can be facilitated by having an example to follow. It is hoped that by providing details of this action research, writing instructors will be empowered to examine the structure of articles in various fields and produce curriculum materials specific to the needs of their students.

2. Theoretical foundation

This section presents a brief literature review of principles from applied linguistics, philosophy, and education that underlie the development of a research-based, pedagogically sound curriculum for engineering writing, particularly engineering graduate students writing RAs in an ELF environment. To ensure that students would be able to emulate the structure of articles in their specialty, not a prescriptive general format, RAs related to each student's research were examined using insights from genre analysis and argumentation theory. Incorporation of established pedagogical principles helped ensure positive learning outcomes.

2.1. Genre analysis

Genre analysis (Swales, 1990) has been used for more than four decades to describe the structure of various genres. The IMRD model (Introduction, Methods, Results, Discussion), the paradigmatic model for RAs, has been found to have wide applicability in many fields, although variations have been noted. Many of the early genre analysis studies examined only a single section of RAs (for a recent survey, see Kanoksilapatham, 2015), perhaps at least partially due to the time required and the quantity of data generated when coding each sentence or phrase to a move and step. Moreover, most research was restricted to articles where the IMRD structure was obvious, with little work on other structures (Yang & Allison, 2004).

The earliest analysis of complete RAs was in the field of medicine (Nwogu, 1997). Yang and Allison (2003) were the first to explicitly discuss the complex interactions between section titles and moves in the Results, Discussion, and Conclusion. Several recent studies claim to examine the structure of the whole RA, but on closer examination have looked only at sections bearing the canonical names or common variants. This may not be a problem in fields like biochemistry (Kanoksilapatham, 2005), chemistry (Stoller & Robinson, 2013), or agriculture (Shi & Wannaruk, 2014), which tend to follow IMRD quite closely. On the other hand, by examining only sections whose titles were readily identifiable as these "major" sections in engineering RAs, Posteguillo (1999) and Kanoksilapatham (2015) overlook both the implications of their absence from many engineering RAs and any moves present in the unexamined sections. Similarly, Cotos et al. (2015), in a massive study of RAs in 30 fields, including some in engineering, restrict their corpus to articles following the IMRD structure.

Even though important differences in RA structure have been documented between closely related fields (e.g. Samraj, 2002; Samraj, 2005), inter- and intra-field differences within engineering and even differences between science and engineering have largely been ignored. For example, Holmes (1997) classifies chemical engineering as science. Similarly, Bruce (2008) used chemical engineering as a representative field of engineering, which he grouped with the hard sciences. It is important to note that chemical engineering RAs typically follow a structure more similar to science than most other engineering fields (Rau, 2020). Anthony and Bowen (2013, p. 13) compare applied mathematics RAs to a "more traditional science/engineering field, namely mechanical engineering." The British Academic Written English (BAWE) corpus groups engineering within the physical sciences and does not distinguish different types of engineering (Jung, 2013).

To my knowledge, only one study (Maswana et al., 2015) has examined entire engineering RAs without restriction on format, calling all sections between the Introduction and Conclusion the "Body." Similarly, Cargill and O'Connor (2013, p. 15) distinguish an IBC format (Introduction, Body, Conclusions) common in "some kinds of engineering, computer science, remote sensing, and physics" without specifying what is included in the Body or discussing the format elsewhere in the book. Maswana et al. conclude: "On its surface, engineering seems to be a unified discipline … However, it includes diverse subdisciplines ranging from observational experimentation to mathematical simulation, which was reflected in the diversity of the results." (2015, p. 9). The authors recommended further study of various subdisciplines and even individual journals to examine variation within engineering. The current study is a first step toward this.

The relationship between genre studies and pedagogy has been recognized for decades (Hopkins & Dudley-Evans, 1988), and many articles mention pedagogical implications. Case studies have been conducted in a classroom context (e.g. Cheng, 2008; Kushner, 1997), and some authors have talked about using a genre-based (Hyland, 2007) or corpus-based (Chang & Kuo, 2011) approach to develop curriculum materials. However, to the best of my knowledge this is the first report of extensive research with the specific goal of producing a research-based curriculum for writing engineering RAs.

2.2. Argumentation theory

While genre analysis focuses on the writer's purposes, rhetorical moves and their linguistic markers, argumentation theory examines the structure of writing from the perspective of logical argumentation. It is well known that scientific research and publishing is based on argumentation (Duschl & Osborne, 2002). Argumentation theory is less concerned with the order of an argument (the rhetorical moves) than the strength of support for the claim in terms of evidence and reasoning: formally, grounds and warrant (Toulmin, 1958).

It has long been realized that persuasion is important in various types of technical writing (Gilsdorf, 1987). Many genre analysis studies have mentioned that RAs are arguments, with minimal elaboration (e.g. Del Saz Rubio, 2011; Koutsantoni, 2006; Thomas & Hawes, 1994). Hyland has frequently addressed argumentation, mostly in terms of the persuasive rhetorical devices used to support an argument (e.g. 1998, 1999, 2004, 2008a, 2008b). Charles (2007), in describing the difference between history and materials science, emphasized the role of argument in history RAs, while Yang and Allison (2004) show its importance in secondary research.

With regard to claims, Myers (1992, p. 296) explained the importance of the "main knowledge claim" near the end of the Introduction. This claim is equivalent to Move 3, Step 2, Announcing principal findings, of the CARS (Creating a Research Space) model (Swales, 1990). Basturkmen also specifically discusses claims (2009), using the metaphor of staking a claim for the "knowledge claim" commonly found in the discussion section of science RAs Basturkmen (2012), the proposed interpretation and supporting evidence. However, the fact that all RAs make and support more than one claim has received little attention in the linguistics literature.

2.3. Need for a new analysis method

RA format in engineering differs between fields, between journals within a field, and even within a journal based on research methodology. It is therefore important that students have a quick, clear, and accurate way to analyze exemplar articles related to their research so they can reproduce that pattern in their own writing.

Move analysis can be used to produce pedagogical materials, but it is primarily a research technique with limited direct use in teaching. It can determine the communicative, rhetorical, and linguistic techniques in RAs (Parkinson, 2017; Yang & Allison, 2003), but does not tell us how the author intended to structure the document (Kanoksilapatham, 2007, pp. 85–86). Moreover, several authors have suggested that only moves, not steps, be used for pedagogical purposes (Chang & Kuo, 2011; Maswana et al., 2015). Yang and Allison (2003) further suggested that self-explanatory names should be used for moves in a teaching context.

Similarly, in this study, move analysis was judged to be too time-consuming for engineering students, and many of the move names suggested are unclear, particularly for those whose first language is not English. Therefore, a simplified component analysis method was developed.

The most important difference between component analysis and traditional genre analysis is that instead of assigning each sentence to a rhetorical move, students identify the main argumentative purpose(s) of each paragraph. This makes the method much faster and easier for students to follow. Nevertheless, since moves usually contain a proposition (Connor & Mauranen, 1999), there is substantial overlap between the components and the moves identified by genre analysis.

Another difference is that whereas corpus analysis is a bottom-up method, and move analysis often uses a mixed bottom-up and top-down approach (Moreno & Swales, 2018), component analysis is a distinctly top-down approach. It begins with the implicit claims of each division, then looks for the component claims and support typically associated with each. This allows students to understand the argument structure of articles, from the divisions down to the level of the paragraph.

2.4. Pedagogical principles

Curriculum design, like engineering design, incorporates or builds on extant elements and ideas, seeking to overcome limitations or drawbacks of the current best solution. But there are always design constraints, tradeoffs where improvement in one area leads to problems in another. A textbook must be simple enough for students to read, but technical enough for instructors to accept. Publishers want a textbook that is broad enough to be used in many different writing classes, yet limit the word count. A curriculum must be based on an accepted theoretical model and fill a niche in the market, just as a research article must fill a gap in the research.

Established pedagogical principles and techniques are mentioned here only briefly as they are not the focus of this article but were important in curriculum development decisions. Ideas from many basic theoretical frameworks, including Bloom's taxonomy (Krathwohl & Anderson, 2009) and Vygotsky's zone of proximal development (ZPD) (Vygotsky, 1978) were subconsciously incorporated. Underlying the entire curriculum are the principles that education should be student-centered and that students need to be active learners (Catalano & Catalano, 1999; Freeman et al., 2014). Specific techniques, such as scaffolding, peer review, and immediate feedback (Lundstrom & Baker, 2009; Rezaei & Shokrpour, 2011; Rollinson, 2005), were purposefully included to enhance student outcomes. Once the textbook was nearing completion, supplemental resources were developed to facilitate use of a flipped classroom (Bishop & Verleger, 2013) or self-instruction. For engineering students in an English as a lingua franca (ELF) environment, I chose to focus on communicative competence rather than grammatical correctness, particularly since non-canonical English is common and accepted in engineering RAs (Rozycki & Johnson, 2013).

3. Methodology

3.1. Action research

This study was conducted as action research, undertaken with a goal of both improving teaching practice and creating new knowledge that can be conveyed to others (McNiff, 2013, p. 13). In action research, the researcher is not an outsider, but a participant. In the context of education, this means the teacher as researcher not only seeks to improve their teaching to meet the needs of their students (action), but also tries to determine why some things work and others do not (research) and publish it, so others can gain from their experience (McNiff & Whitehead, 2009, p. 5). This has become a widely accepted technique in educational research. In this case the action largely preceded the reporting of the research. Following the accepted format for action research (McNiff & Whitehead, 2009, p. 39), this section will be written in the first person.

3.1.1. Action researcher

The author of this study served multiple roles: action researcher, curriculum developer, and instructor. With a background in science and science education, I had previously developed standards-based curricula and materials in an ELF context. As a freelance editor I helped researchers publish in many fields in the natural sciences, social sciences, and applied mathematics, but not engineering. When asked to teach scientific and engineering writing, I found that the structure of engineering articles differed markedly from the IMRD (or IMRaDC) structure in writing textbooks, but that little research had been done on the engineering RA genre. I thus began my own study, concurrently developing teaching materials reflecting my ongoing understanding of both the structure of the articles and the needs of the students.

3.1.2. Setting and students

I taught "Scientific writing" in the extension program at a national university in central Taiwan once per academic year for four years. The course was an evening elective course, 2 h per week for 12 weeks, that did not show on students' transcript or count toward graduation. Since it was non-credit and ungraded, there was little motivation for students to work outside of class. Despite the course title, most students were from engineering, while others were from business and humanities. Classes were conducted in English, using a textbook designed for ELF (Glasman-Deal, 2010) for the first three semesters and the first draft of my textbook for the last.

Every semester since spring 2016 I have taught "English technical writing" in the department of electrical engineering (EE) at the same university, to prepare students to write RAs, conference papers, and possibly theses in English. This is a graduate-level elective course with one 3-h class per week for 16 weeks. Most students were from EE, including some working on biomedical engineering (BME) applications, with others from chemical engineering (CE), mechanical engineering (ME), computer science and information engineering (CSIE) and various branches of science. Most were seeking a master's degree, some a doctoral degree, with a few undergraduates. The majority were from Taiwan, but many were international students. The gender distribution was similar to the overall enrollment in the engineering programs, i.e. predominantly male. Classes for spring and fall 2016 were capped at 20 students, and thereafter limited to 10 students per class to ensure sufficient time to talk with each student each week.

The two stages in each class are shown in Figure 1. Students first used component analysis to analyze the structure of exemplar articles related to their research, then used that knowledge to write about their own research. When I began

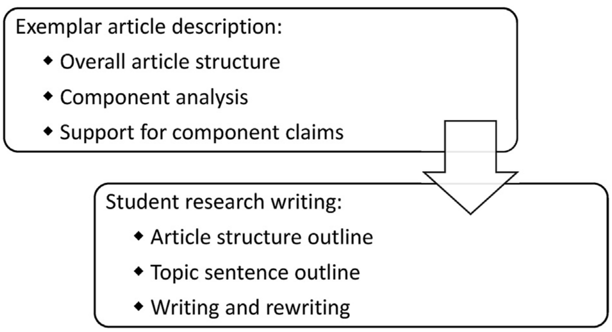

Figure 1. Stages of instruction.

teaching in EE, the intended audience was advanced students ready to write a whole RA. However, many students had not done enough research to complete the task successfully, including master's students in their first semester. Thus, the decision was made to offer a separate advanced class, with students in the basic course asked to write only an Introduction.

3.1.3. Data sources and analysis

Open-ended qualitative action research was conducted to understand the structure of engineering research articles, develop the component analysis method, and improve the curriculum materials. As instructor, I had access to and control over all materials used in the class.

In development of the component analysis method, each of the more than 150 graduate engineering students taking the course during the study period chose three articles related to their thesis research and analyzed them according to the method in the textbook that year. In this way over 500 engineering RAs were analyzed, with the results reported by each student in their exemplar article description. Each semester, the categories and their descriptions were modified to better match the RAs and improve agreement between instructor and students on how to analyze each paragraph.

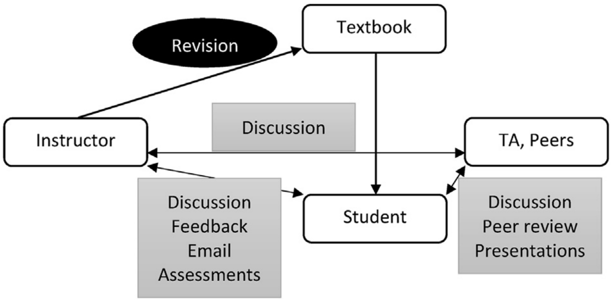

Figure 2. Interactions during curriculum development.

A summary of the interactions between participants is shown as Figure 2. Each week students were asked to read a portion of the textbook (typically one chapter) before class. For the first few classes each semester, I would summarize the main points in a PowerPoint presentation. In later classes a student would prepare and present the summary, with clarification as needed. The time spent on this was greatly reduced after production of supplemental material allowed implementation of a flipped classroom model. Extensive class time was devoted to student work on exercises from the textbook. During that time students would discuss questions with one another, the teaching assistant (TA) and the instructor. At the end of each class, students were asked to write feedback to express what they learned, liked, disliked, or had questions on during the class. Questions raised in the weekly feedback or later in the week via email were answered immediately via email and discussed in class the following week.

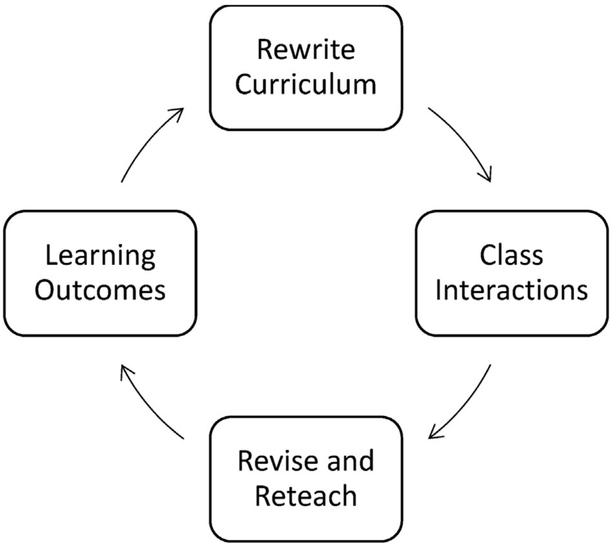

Figure 3. Curriculum development cycle.

Both the textbook and assessments in it were modified each semester in response to student feedback and learning outcomes in two stages, as shown in Figure 3. Triangulation between individual discussions, student presentations, and assignments ensured that the revisions led to continual improvement in comprehension and performance from year to year. When interactions with students in class indicated questions, misconceptions, or topics that were hard to understand, these were documented immediately with handwritten notes in the appropriate portion of the textbook. Written assignments, submitted every two to three weeks, revealed further misunderstandings or problems, as did student oral presentations. Any problems identified were discussed with students and the component analysis, textbook, and assignments were revised for accuracy and clarity.

3.2. Timeline of the study

Important steps in development of the curriculum are shown diagrammatically in Table 1. Each will be discussed further in section 4.

Table 1
Timeline of major events in the study.

	Component Analysis	Textbook & Assessment	English as a lingua franca
Extension program			
S12[a]	Not all RAs are IMRD		
F12	IPTC[b] proposed		
F13			
F14		First printed draft	Topic sentences
Electrical engineering			
S16			7Cs of Change
F16	Implicit claims	Argument theory	
S17	Metadiscourse out	Sentence patterns	Hints, Teacher notes
F17	Component claims		Callouts, Glossary
S18			
F18	Past research out	Reorganization	
S19	Framework added	Component markers	
F19		Published textbook	

[a] Spring/Fall semester 20xx.
[b] Introduction, Process, Testing, Conclusion: see section 4.1.2.

To ensure accuracy, an understanding of the structure of engineering RAs was developed in constant interaction with students and subject area specialists. Each student chose three exemplar articles related to their thesis research, which they analyzed according to the method of component analysis in the version of the textbook current at that time, then discussed their analysis with me. When we could not agree or understand the structure of an article, they were directed to ask their advisor and report back to me. This co-construction of typical RA structure between a writing instructor and subject specialists improved the reliability of the results. Details of this process are presented in section 4.1.

Each semester the curriculum materials, both the text and assessments, were rewritten or modified based on student feedback and the learning outcomes from the previous semester, as described in section 4.2. Textual organization, supplemental materials and activities to assist ELF students were developed contemporaneously, as discussed in section 4.3.

4. Results and Discussion

This section presents evidence of achievement of the goals of the action research. The instructor worked closely with students to analyze articles, modify analysis procedures, and clarify the text and assignments. The first three subsections are related to the three research goals, demonstrating 1) development of component analysis, incorporating ideas from genre analysis and argumentation theory, to describe exemplar articles, 2) how assessment was used to both evaluate student achievement of learning goals and improve the curriculum, and 3) design of supplemental materials to assist ELF students and their instructors. This is followed by a brief discussion of elements leading to success and limitations of the study.

4.1. Component analysis

Component analysis focuses on identifying what claims writers need to include, where to place them in an article, and the importance of connecting claim and evidence. Once they knew what to include, students were able to choose appropriate linguistic strategies for making and supporting claims based on the models they saw in their exemplar articles and examples in the textbook from other engineering RAs.

4.1.1. Overall format of engineering RAs

Analysis of engineering RAs began informally with the first class in the extension program, in spring 2012, when a student said that his article did not fit the IMRD format. Most noticeably, the Methods division, which in scientific writing is generally short and written in a very condensed style, was replaced by an extensive description of the new design written in extended style.

An analogous prototypical format for engineering articles, IPTC (Introduction, Product or Process, Testing, Conclusion), was proposed in fall 2013. Justification for designation as a separate format is presented elsewhere (Rau, 2020). In fall 2014, the first draft version of the textbook distinguished the “sections” named by the author from “divisions” as conceptual units which might include more than one section.

Evidence from student analysis of exemplars has shown that while EE, ME, and CSIE typically follow IPTC, CE and BME tend to follow IMRaDC. Mathematical or theoretical papers often follow an IPC (Introduction, Proof, Conclusion) format, since no empirical testing is required with a mathematical proof. Some RAs do not follow these formats, particularly in industrial journals, where much ME research is published. Enough components differ for this to be considered a separate genre. Similarly, survey articles, brief articles, and others appearing in engineering journals require a separate genre designation (Rau, 2020 p. 7, see also Part 3, Exploring different genres).

4.1.2. Component categories

Initially, the topics expected in each division were drawn from a textbook on scientific writing, with modification for engineering. For example, for the Introduction the topics were 1) establishing significance, 2) describing related research, 3) identifying a gap, and 4) summarizing the paper (modified from Glasman-Deal, 2010, p. 24). These topics changed each year, with the addition of others found in student exemplars.

Table 2
Fifteen components that might appear in IMRD or IPTC and their most common location (Modified from the draft textbook of fall 2016).

Component	Division in	
	IMRDC	IPTC
1. Importance of the work	I	I
2. Need for the work	I	I
3. Research gap	I	I
4. Organization	I	I
5. Past research	I	I, P
6. Connection between past and current research	I	I, P
7. Terminology or notation	I	I, P
8. Design summary	M	P
9. Design rationale	M	P
10. Design details	M	P
11. Testing introductory summary	R	T
12. Results	R	T
13. Comparisons	R, D	T
14. Discussion	D	T
15. Conclusions	C	C

In spring 2016 a unified list of components found in research articles was proposed, with locations differing in the two formats, as shown in Table 2. This list was strongly influenced by the exemplars analyzed to date. For example, the placement of components 5 and 6 was influenced by students from CSIE, whose articles regularly include a brief Introduction followed by two sections with extensive citations, Related work and Preliminaries. Description of the components changed in response to student questions or misunderstanding, and a growing understanding of the argument structure of engineering RAs. Over time, both the number and scale of the changes decreased.

4.1.3. Claims and component claims

The change from an ungraded extension class to a graded class in the EE department in spring 2016 caused students to take the course more seriously, ask more questions and make more comments on the textbook. This feedback led to foregrounding the idea that all research articles are (or should be) structured as arguments, making claims supported by evidence and reasoning, and that each division supports one basic implicit claim. In the textbook, “argument structure” is used in the sense of the structure of an argument according to argument theory, not in the sense the term is used by formal linguists of the arrangement of lexical items within a sentence.

This led to the realization in spring 2017 that most of the components listed were component *claims* of the three implicit claims of the three main divisions. On the other hand, metadiscoursal elements such as summary paragraphs that are not claims were removed from the list. Past research, which supports claims, was removed the following year. Student response to this recharacterization of components was overwhelmingly positive.

Furthermore, different implicit claims in science and engineering lead to slight differences in the location of component claims (Rau, 2020), based on which components are related to each of the implicit claims. A summary of the relation between the main implicit claims, component claims, and support in each division in IMRD and IPTC is shown in Tables 3 and 4.

Table 3
Implicit claims, component claims, and support for each division in a typical science article, IMRD (Modified from Rau, 2020).

Implicit claim of each division and component claims	Support
Introduction: We have identified an important unanswered question	
1. Importance: The work is important to society or the field	(Background knowledge)
2. Need: A gap exists in current knowledge or understanding	Past research
3. Research goal: We answer the question or improve understanding	
4. Framework: The research is based on an accepted model[a]	Past research
Materials and Methods: We have gathered data in a valid, reliable way	
5. Research details: Care was taken to ensure good results	Current research details
6. Testing methods: We can predict results based on the model	Current testing methods
Results and Discussion: We have a good explanation for the data	
7. Data patterns: A pattern can be discerned in the data	Current data
8. Comparisons: Data [support/question] previous work	Current data, past research
9. Interpretations: There is a reasonable cause for the results	Reasoning
10. Conclusion: The question has been answered	

[a] Often the last past research mentioned before the research goal.

Table 4
Implicit claims, component claims, and support for each division in a typical IPTC engineering article (Modified from Rau, 2020).

Implicit claim of each division and component claims	Support
Introduction: We have identified an important unresolved problem	
1. Importance: The problem is important to society or the field	(Background knowledge)
2. Need: The current solution is limited or less than ideal	Past research
3. Research goal: We propose a better solution to the problem	
Product or Process: We have designed a workable solution to the problem	
4. Framework: The research is based on an accepted theoretical model	Past research
5. Research details: The solution developed is workable	Current research details
Testing and Conclusion: Our solution is better than existing solutions	
6. Testing methods: Testing followed verifiable procedures	Current testing methods
7. Data patterns: A pattern can be discerned in the data	Current data
8. Comparisons: The solution is better than previous solutions	Current data, past research
9. Interpretations: There is a reasonable cause for the results	Reasoning
10. Conclusion: The solution is an improvement on the current best design	

After past research was removed from the list, framework was added as a component to differentiate places where past research was cited to show the limitations of previous work (Need) from those laying the foundation for the present work (Framework). Since the difference is determined largely by the author's stance toward past research, it had not been distinguished before, although specification of the underlying theoretical model is a vital part of research writing.

In the final version, ten components were identified. In determining how many categories to use, the goal was to come up with a unified list such that most RAs would contain almost every component, and each component would represent a claim, not support. The underlying intent is for each component to represent a distinct epistemic category, which together cover all the categories of claims common in RAs. Whether this has been achieved awaits further study.

4.1.4. Component markers

The final problem was how to help students recognize the components, especially if they did not occur in the expected order. In spring 2017 sentence patterns were added to the textbook, based on the idea of sentence templates (Cargill & O'Connor, 2013, p. 126). This name proved confusing to students, to whom it implied a grammatical pattern. It was thus later changed to component markers, to highlight that these are groups of words they could use to recognize the components as well as reuse in their own writing, known to linguists as lexical bundles (Biber et al., 1999; Cortes, 2013; Hyland, 2008a).

4.2. Curriculum development via outcome-based assessment

Assessment sought to measure the degree to which students could use component analysis to analyze exemplar articles, then use that information to write their own RAs. Assignments were created based on the information in each chapter, then modified and clarified based on student performance. Poor performance of students on a written assessment was often the first indication that either the related text content or the assignment required revision. Discussion with the students after the assignment was returned helped clarify where the problem lay.

Assignments were designed to build on one another sequentially, with higher standards for each in turn. The assignments in the first part of the course (describing exemplars) gave students the skills necessary to complete the second part (writing their research). During the first half of the semester students were also taught how to use advanced features of MS Word and how to incorporate citations and references from a reference manager. Students frequently commented that this was very useful, so demonstration of these skills was incorporated into the rubric.

The assignments were scaffolded. Each week in the first half of the semester the students completed an exercise for one exemplar article in class and checked the results with the instructor to make sure they understood both the content and the assignment. They then did the same thing on their own for two more exemplars. The following week that work was checked, revised, and they went on to the next chapter. Each assignment built on the previous week, and all were compiled into a complete description of their exemplars at midterm. A similar process of writing, adding, and rewriting was used in the second half of the course for their own research, based on the pattern they discerned in exemplars from their own subfield.

Assignments were improved, shortened, and clarified over time. For example, for the first written exercise (describing the overall structure of three articles) the assignment in spring 2016 was three paragraphs long, making it hard for students to know exactly what was required. This was later broken into numbered parts, interspersed with hints to ensure success (Appendix A). The numbering made the assignment clearer and allows teachers to choose to assign or not assign certain parts. Since this is the first written assignment, some hints are specific to this assignment while others are related to the whole course. Clearly defined holistic rubrics have also undergone refinement each year, becoming more consistent and easier to use. This has continued after the supplemental materials were published online. For the current version, please contact the author.

Concurrent changes in component analysis and related assignments gradually made it easier to assess student understanding of article structure. For the first three semesters the course was taught in EE, students made a table showing which components they found in each paragraph, but were not asked to cite examples, so it was difficult to know whether they really understood the concept. In fall 2017, after the idea of sentence patterns (later component markers) was introduced, with examples in the textbook, students were asked to identify examples of each from their exemplars. This made it clear whether students understood the components or not (Appendix B).

Similarly, assignments have become more concrete in the second half of the course, particularly with respect to prewriting. A method was proposed whereby students begin with an argument structure outline based on the structure of their exemplar articles, listing the number of paragraphs devoted to each component. For each paragraph they then wrote a topic sentence before writing more.

As would be expected, as the assignments became clearer, more students were able to produce work meeting the expectations. Moreover, the instructor gradually realized what type of scaffolding was needed to allow students to succeed. As these elements were built into the teaching, students produced better written assignments. Since teaching, textbook, and assignment clarity were improved simultaneously, it was impossible to separate their effects.

4.3. Supplemental material and activities for ELF

To assist students using English as a lingua franca, many elements were added to the curriculum in class as well as the textbook and supplemental materials. These covered all four language skills: reading, writing, listening, and speaking. These materials also supported use of the curriculum in different contexts, whether in a class taught in a writing center by a writing instructor, a department by a subject specialist, or a student learning independently.

To help students read effectively, the first line of each paragraph in the textbook was purposefully written as a topic sentence, wherever possible. Common vocabulary easily understood by engineering students was used instead of linguistic terms. The 7Cs of Change (Coherence, Conciseness, Connection, Connotation, Consistency, Correctness, Collaboration) were developed as a mnemonic for stages of rewriting. Hints were added to help students to complete assignments. To make it easier to find main points, callout boxes were added. Notes for teachers were also added, based on the experience of the author while teaching the class. A balance had to be struck in the textbook between clarity of explanation and brevity. Questions from students about the textbook were used to guide this process.

Moreover, some writing topics that might have been minimized in a book for those using English as a first language received far greater attention. Some of this material was later moved from the textbook to the supplemental online material on the publisher's website.[1]

Many classroom activities were incorporated into the curriculum to enhance listening and speaking. The first day of class a self-designed temperament analysis helped students recognize their strengths and weaknesses relative to research and writing. From the second class I began to ask questions about the text, employing the "Think, Pair, Share" strategy. This allowed students time to formulate their answer, avoiding the awkward silence that often follows teacher questions, especially in an Asian ELF context.

Mixing activities that get students talking were used to pair students for peer review. For example, each student was given a card with a picture of a star with a happy face and had to find the other person with the matching picture by describing their star in English. Students regularly reported these were their favorite part of that week's class.

Peer review provided multiple benefits including another pair of eyes to spot errors, basic training in the importance of collaboration and the review process, and greater awareness of differences in the format of RAs, even between subfields within a department. Initially done orally in class, later students were asked to provide written feedback to their partner.

[1] https://www.routledge.com/Writing-for-Engineering-and-Science-Students-Staking-Your-Claim/Rau/p/book/9781138388253#eresources.

Switching partners approximately every three weeks allowed exposure to other RA formats, commentators, and variants of English, depending on class composition.

To prepare students to present their work at an international conference, two students were assigned each week to summarize the material from the textbook and show how to do the exercise(s) in the chapter. There was also a final oral presentation, either a report on what they learned in the class and how they will use it, for first semester students, or a conference-style presentation on their research.

Immediate feedback was implemented by talking to every student in class to ensure they were going the right direction. Weekly written feedback allowed students to ask questions they were not able to get answers to in class. By answering those questions, comments, or criticisms immediately by email or the following week in class, I affirmed their importance.

After completion of the textbook, in conjunction with moving to a flipped classroom approach in fall 2017, audio PowerPoint summaries were prepared for each chapter[1] to allow students to quickly understand the main points of the chapter in a format similar to a lecture, but with the option of stopping or replaying it at any point. The effectiveness of the PowerPoints is obvious from the fact that many students chose to print them and refer to them in class, even pointing things out to their partner on them.

In fall 2019 a Massive Open Online Course (MOOC) was filmed based on the first nine chapters of the textbook, showing students how to analyze the structure of exemplar articles, then use that as a basis for their own writing. In the MOOC I summarized the main ideas of each chapter, while graduate students from EE, ME, and CE demonstrated how to use the material to complete the main exercise in that chapter. Beginning in spring 2020, the MOOC was made available to both students on campus and the public as an optional way of learning the material.[2]

4.4. Elements leading to success

Student performance in the course and student evaluation of the course have both been high from the beginning, making it difficult to objectively evaluate improvement over time or what may have caused it, as every element in the class has changed every semester. Nevertheless, five aspects stand out as having a large effect when developing and teaching an engineering research article writing course.

First, in terms of determining the structure of engineering RAs, my background was advantageous. My editing experience made me aware of the degree of variation in RA format. As an outsider, I was able to evaluate the structure more objectively than subject area specialists, but my science training allowed me to read and understand the content of the articles, apart from the higher mathematics. Curriculum developers lacking similar experience may need to partner with a subject area specialist to confirm their observations.

Second, in terms of student analysis of exemplars, the identification of components as sub-claims of the implicit claims made in each division, each requiring different types of support, helped students understand *why* things should go in different places, instead of simply following a prescriptive rule. Related to that is the provision in the textbook of examples of component markers from engineering. This allowed students to find the components even in articles that did not follow the prototypical structure, as well as use the markers in their own writing.

Third, in terms of learning to write in a format that would be accepted by the disciplinary community, allowing each student to use exemplar articles related to his or her own research helped them identify the characteristics of a prototypical article in their subfield, since there are vast differences within a discipline. A further crucial modification was the idea of writing an argument structure outline, based on the structure of the exemplars, followed by writing topic sentences for each paragraph. This greatly improved the organization of the Introductions, reducing the need for revision.

Fourth, in terms of curriculum improvement, making notes immediately any time a problem was noted, whether during class or when grading an assignment, guaranteed that it would not be forgotten. Revising that section as soon as possible thereafter and talking with students about the revision ensured that the concerns or misconceptions were addressed. Working closely for many years with students and subject specialists allowed me to test and modify the component categories, descriptions, curriculum materials, and assessments multiple times.

Finally, in terms of teaching, implementing a flipped classroom doubled the time available to consult individually with students, making it far more likely that their problems and questions were resolved in class. Explicit directions for the assignments, clear rubrics, and samples of previous student work, including those of the TAs in the MOOC, also helped ensure students understood the goal for each chapter.

4.5. Limitations of the study

This paper has only examined the process of curriculum development. Evaluation of the effectiveness of that curriculum and elements appreciated by the students awaits further study. The component analysis approach has been used successfully in one-day workshops with students from other fields, with only minor modifications in subcomponent categories, but more work is needed to extend its applicability.

[2] https://taiwanlife.org/admin/tool/mooccourse/mnetcourseinfo.php?hostid=7&id=1980.

All decisions in curriculum development were based on practical pedagogy, not on a commitment to any theoretical framework. In the course of the research, a new theoretical framework emerged to explain the differences in structure of research articles in different fields (Rau, 2020, pp. 20–25). This framework is still under development.

At the behest of the publisher, material on other genres was added to increase the utility of the textbook. This is an added hurdle that curriculum developers may face. While these genres are not supported by the degree of research accorded to RAs, I have had personal experience with most, either as a teacher or editor. For each, their similarity to or difference from RAs is related to differences in goal, audience, and evaluation criteria. The accuracy and effectiveness of this material has not been evaluated, as it does not fall within the scope of the classes I am currently teaching, but that would be a fruitful topic for future research.

5. Conclusion

This article has presented the results of an eight-year action research program during which component analysis, a simplified method of genre analysis combined with ideas from argumentation theory, was developed with categories and descriptions co-constructed by the author and students. Analysis of over 500 RAs in conjunction with novice engineers, with backing from their advisors, helped clarify how the prototypical structure varies in five engineering disciplines (EE, CSIE, ME, CE, and BME). Concurrently, a curriculum was developed to teach engineering graduate students to write RAs in the format expected by their subfield based on analysis of exemplar articles. This research may be useful to writing instructors seeking to develop a curriculum for students in other fields or for genres that have received little attention.

Further research needs to be done on the genre of RAs in engineering, to elucidate how much of the variation observed is due to the field, subfield, journal, first language of the author, or author preference. There is clearly a tendency in engineering for key researchers to influence not only the direction of the research, but also the structure of articles in that sub-field. Moreover, the components identified need to be explored further to determine their generalizability to other fields, and whether they truly cover all epistemic categories without overlap. This will require research on entire research articles rather than isolated sections or divisions.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The author is also the author of the published textbook and material described herein, and will receive a small royalty from any sales.

Acknowledgements

I would like to thank the editor and reviewers for not only clear and extensive comments, but also for helping a new researcher in this field understand how the expectations differ from engineering.

Appendix A and Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esp.2020.12.001.

References

Anthony, L., & Bowen, M. (2013). The language of mathematics: A corpus-based analysis of research article writing in a neglected field. *Asian ESP Journal, 9*(2), 5-25.
Basturkmen, H. (2009). Commenting on results in published research articles and masters dissertations in Language Teaching. *Journal of English for Academic Purposes, 8*(4), 241-251.
Basturkmen, H. (2012). A genre-based investigation of discussion sections of research articles in dentistry and disciplinary variation. *Journal of English for Academic Purposes, 11*(2), 134-144.
Biber, D., Johansson, S., Leech, G., Conrad, S., & Finegan, E. (1999). *Longman grammar of spoken and written English*. Essex, England: Pearson.
Bishop, J. L., & Verleger, M. A. (2013). The flipped classroom: A survey of the research. In *Paper presented at the ASEE national conference proceedings*. Atlanta, GA.
Bruce, I. (2008). Cognitive genre structures in methods sections of research articles: A corpus study. *Journal of English for Academic Purposes, 7*(1), 38-54.
Cargill, M., & O'Connor, P. (2013). *Writing scientific research articles: Strategy and steps*. West Sussex, UK: John Wiley & Sons.
Catalano, G. D., & Catalano, K. (1999). Transformation: From teacher-centered to student-centered engineering education. *Journal of Engineering Education, 88*(1), 59-64.
Chang, C.-F., & Kuo, C.-H. (2011). A corpus-based approach to online materials development for writing research articles. *English for Specific Purposes, 30*(3), 222-234.
Charles, M. (2007). Argument or evidence? Disciplinary variation in the use of the noun that pattern in stance construction. *English for Specific Purposes, 26*(2), 203-218.
Cheng, A. (2008). Analyzing genre exemplars in preparation for writing: The case of an L2 graduate student in the ESP genre-based instructional framework of academic literacy. *Applied Linguistics, 29*(1), 50-71.

Connor, U., & Mauranen, A. (1999). Linguistic analysis of grant proposals: European union research grants. *English for Specific Purposes, 18*(1), 47-62.
Cortes, V. (2013). The purpose of this study is to: Connecting lexical bundles and moves in research article introductions. *Journal of English for Academic Purposes, 12*(1), 33-43.
Cotos, E., Huffman, S., & Link, S. (2015). Furthering and applying move/step constructs: Technology-driven marshalling of Swalesian genre theory for EAP pedagogy. *Journal of English for Academic Purposes, 19*, 52-72.
Del Saz Rubio, M. M. (2011). A pragmatic approach to the macro-structure and metadiscoursal features of research article introductions in the field of Agricultural Sciences. *English for Specific Purposes, 30*(4), 258-271.
Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education, 38*, 39-72.
Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences, 111*(23), 8410-8415.
Gilsdorf, J. (1987). Writing to persuade. *IEEE Transactions on Professional Communications*, (2), 68-73.
Glasman-Deal, H. (2010). *Science research writing for non-native speakers of English*. London: World Scientific.
Holmes, R. (1997). Genre analysis, and the social sciences: An investigation of the structure of research article discussion sections in three disciplines. *English for Specific Purposes, 16*(4), 321-337.
Hopkins, A., & Dudley-Evans, T. (1988). A genre-based investigation of the discussion sections in articles and dissertations. *English for Specific Purposes, 7*(2), 113-121.
Hyland, K. (1998). Persuasion and context: The pragmatics of academic metadiscourse. *Journal of Pragmatics, 30*(4), 437-455.
Hyland, K. (1999). Disciplinary discourses: Writer stance in research articles. In C. Candlin, & K. Hyland (Eds.), *Writing: Texts, processes and practice* (pp. 99-121). London: Longman.
Hyland, K. (2004). A convincing argument: Corpus analysis and academic persuasion. In T. A. Upton (Ed.), *Discourse in the professions: Perspectives from corpus linguistics* (pp. 87-112). Amsterdam: John Benjamins Publishing.
Hyland, K. (2007). Genre pedagogy: Language, literacy and L2 writing instruction. *Journal of Second Language Writing, 16*(3), 148-164.
Hyland, K. (2008a). As can be seen: Lexical bundles and disciplinary variation. *English for Specific Purposes, 27*(1), 4-21.
Hyland, K. (2008b). Persuasion, interaction and the construction of knowledge: Representing self and others in research writing. *International Journal of English Studies, 8*(2), 1-23.
Jung, C. K. (2013). Genre analysis. Undergraduate engineering laboratory report (UELR). *Korean Journal of Applied Linguistics, 29*(3).
Kanoksilapatham, B. (2005). Rhetorical structure of biochemistry research articles. *English for Specific Purposes, 24*(3), 269-292.
Kanoksilapatham, B. (2007). Rhetorical moves in biochemistry research articles. In D. Biber, U. Connor, & T. A. Upton (Eds.), *28. Discourse on the move: Using corpus analysis to describe discourse structure* (pp. 73-119)John Benjamins.
Kanoksilapatham, B. (2015). Distinguishing textual features characterizing structural variation in research articles across three engineering sub-discipline corpora. *English for Specific Purposes, 37*, 74-86.
Koutsantoni, D. (2006). Rhetorical strategies in engineering research articles and research theses: Advanced academic literacy and relations of power. *Journal of English for Academic Purposes, 5*(1), 19-36.
Krathwohl, D. R., & Anderson, L. W. (2009). *A taxonomy for learning, teaching, and assessing: A revision of bloom's taxonomy of educational objectives*. Longman.
Kushner, S. (1997). Tackling the needs of foreign academic writers: A case study. *IEEE Transactions on Professional Communications, 40*(1), 20-25.
Laplante, P. A. (2018). *Technical writing: A practical guide for engineers, scientists, and nontechnical professionals*. Boca Raton, FL: CRC Press.
Lundstrom, K., & Baker, W. (2009). To give is better than to receive: The benefits of peer review to the reviewer's own writing. *Journal of Second Language Writing, 18*(1), 30-43.
Maswana, S., Kanamaru, T., & Tajino, A. (2015). Move analysis of research articles across five engineering fields: What they share and what they do not. *Ampersand, 2*, 1-11.
McNiff, J. (2013). *Action research: Principles and practice*. London: Routledge.
McNiff, J., & Whitehead, J. (2009). *You and your action research project*. London: Routledge.
Moreno, A. I., & Swales, J. M. (2018). Strengthening move analysis methodology towards bridging the function-form gap. *English for Specific Purposes, 50*, 40-63.
Myers, G. (1992). 'In this paper we report…'': Speech acts and scientific facts. *Journal of Pragmatics, 17*(4), 295-313.
Nwogu, K. N. (1997). The medical research paper: Structure and functions. *English for Specific Purposes, 16*(2), 119-138.
Parkinson, J. (2017). The student laboratory report genre: A genre analysis. *English for Specific Purposes, 45*, 1-13.
Posteguillo, S. (1999). The schematic structure of computer science research articles. *English for Specific Purposes, 18*(2), 139-160.
Rau, G. (2020). *Writing for engineering and science students: Staking your claim*. London: Routledge.
Rezaei, M., & Shokrpour, N. (2011). Teacher vs. Peer scaffolding modes in L2 writing classes: A consideration of genre approach to writing. *Indonesian JELT, 7*(2), 40-64.
Rollinson, P. (2005). Using peer feedback in the ESL writing class. *ELT Journal, 59*(1), 23-30.
Rozycki, W., & Johnson, N. H. (2013). Non-canonical grammar in Best Paper award winners in engineering. *English for Specific Purposes, 32*(3), 157-169.
Samraj, B. (2002). Introductions in research articles: Variations across disciplines. *English for Specific Purposes, 21*(1), 1-17.
Samraj, B. (2005). An exploration of a genre set: Research article abstracts and introductions in two disciplines. *English for Specific Purposes, 24*(2), 141-156.
Shi, H., & Wannaruk, A. (2014). Rhetorical structure of research articles in agricultural science. *English Language Teaching, 7*(8), 1-13.
Silyn-Roberts, H. (2013). *Writing for science and engineering: Papers, presentations and reports*. Newnes.
Stoller, F. L., & Robinson, M. S. (2013). Chemistry journal articles: An interdisciplinary approach to move analysis with pedagogical aims. *English for Specific Purposes, 32*(1), 45-57.
Swales, J. M. (1990). *Genre analysis: English in academic and research settings*. Cambridge: Cambridge University Press.
Thomas, S., & Hawes, T. P. (1994). Reporting verbs in medical journal articles. *English for Specific Purposes, 13*(2), 129-148.
Toulmin, S. (1958). *The uses of argument*. Cambridge: Cambridge University Press.
Vygotsky, L. S. (1978). In A. R. Luria, M. Lopez-Morillas, M. Cole, J. V. Wertsch, T. M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.), *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.
Yang, R., & Allison, D. (2003). Research articles in applied linguistics: Moving from results to conclusions. *English for Specific Purposes, 22*(4), 365-385.
Yang, R., & Allison, D. (2004). Research articles in applied linguistics: Structures from a functional perspective. *English for Specific Purposes, 23*(3), 264-279.

Gerald Rau has a background in science and science education and taught science for fifteen years. He did freelance academic editing for over fifteen years and has taught academic writing for eight years. He has published in science, science teaching, philosophy of science, and linguistics.