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Development and Uses of Iterative Systematic Literature Reviews in Electrical Engineering Education

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Abstract

It is expected that most, if not all, graduate students will possess skills necessary for doing literature reviews. It is less clear how to teach these skills most effectively especially to students who are area novices and unfamiliar with review process. Systematic literature reviews offer a solid instructional framework which can be implemented across curriculum and offer an opportunity to teach course material differently so that student learn not just the literature review technique itself but also some segment of the course material. Our pilot study investigated issues related to practical implementation of systematic literature reviews in two classes, with different course lengths and purpose of review assignments. Our initial results are encouraging: students' self-efficacy with respect to ability to do reviews improved and they think that this skill is useful. We have developed a new rubric for evaluation of final reports as well as weekly schedule of tasks.

Keywords: *systematic literature reviews, rubrics.*

1. Introduction

Literature review is a skill that most faculty would profess all research-oriented graduate students should have. Students can typically acquire this skill through a) mentoring, and/or b) course on research methods. The latter can be generic or taught within a department. There are many resources on writing literature reviews, from campus writing centers to books such as Machi and McEvoy [1]. One would also assume that this is among the very first tasks that research-oriented students would undertake. However, our brief and preliminary survey of students in two graduate courses in electrical and computer engineering department showed that they have very little to no experience in performing literature reviews, and discussions with other faculty confirmed that students in their classes are equally unprepared. The most obvious use of training graduate students in performing literature reviews is in helping them write their thesis or dissertation. Literature reviews, however, have other uses, such as starting a new research area by identifying holes in the existing literature or summarizing one's own research area. It has also been argued that a variant of literature review, so-called "systematic literature review" (SLR) can help students publish their first original work and transition them from novice to knowledgeable [2][3]. Finally, systematic literature reviews are research area by themselves, although they are less common in engineering than in areas like medicine, psychology or education.

It is, therefore, appropriate to intentionally train and educate students in performing literature reviews in general and SLR in particular. One possible approach is to design a research methods course that also covers SLR topics or maybe even have a separate course or workshop on SLR. Experience with other so-called soft-skills, such as technical writing, suggests that learning how to do literature reviews and SLR can best be accomplished by incorporating them in various courses across the curriculum and not by designing a separate course [4]. In this report, however, we will concentrate on the course-level implementation. Furthermore, there seems to be a lack of familiarity among engineering faculty regarding differences between narrative and systematic literature reviews (SLR). In this report we will clarify the differences and explain uses of SLR in different fields and how it could be used in engineering education.

In the following we will present the case that iSLR is a useful educational tool in electrical engineering when used either as part of research-like project on a specific subject matter covered in a course, or as a standalone project. Expected educational benefits include improved critical thinking and writing, increased motivation, life-long learning skills, increased topic coverage and depth. We modified two graduate courses to include SLR: a) solid-state electronics course for MS and PhD electrical engineering students, and b) microwave circuit design sequence for graduate students and undergraduate seniors. The rest of the paper is organized as follows: section 2. gives an overview of uses of SLR in other disciplines, section 3. discusses iSLR implementation, section 4. presents some assessment data and analysis, and section 5. provides conclusions.

2. Systematic literature reviews in different disciplines

A lot of resources are available for writing literature reviews and there are general and field-specific books that cover the process, e.g. [1]. Typically, these books are aimed at graduate students preparing their theses or dissertation proposals, but they do not discuss SLR- or iSLR-based approaches. Given that the use of SLR or iSLR as a pedagogical tool is relatively recent, it is important to properly distinguish SLR from other forms of review and to understand where it comes from, its history, and how it is used in different disciplines. One discipline using SLR extensively is medicine where the purpose of SLR is not to just summarize the state-of-the-art at a given point in time, but also to provide meta-analysis of available data, which then leads to some conclusions and policy decisions. Given the potential impact and importance of such studies, there was a need to provide specific guidance with respect to how such studies should be performed and reported, resulting in two statements: QUORUM (Moher et al. [5]) and PRISMA (Moher et al. [6]). PRISMA statement defines SLR as:

A systematic review is a review of a clearly formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyze data from the studies that are included in the review. Statistical methods (meta-analysis) may or may not be used to analyze and summarize the results [6].

The PRISMA statement provides guidelines on seven areas that SLR studies should address: Title, Abstract, Introduction, Methods, Results, Discussion, and Funding. There is a total of 27 items in a checklist format. For example, it is required that an SLR study:

- *Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.*
- *State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis) [6].*

In software engineering procedures and guidelines on how to conduct SLR have been available since 2004 [7][8] and there is a similar attempt to define SLR:

A systematic review is a means of evaluating and interpreting all available research relevant to a particular research question, topic area, or phenomenon of interest. Systematic reviews aim to present a fair evaluation of a research topic by using a trustworthy, rigorous, and auditable methodology [7].

While their emphasis and wording is different, both definitions are attempting to explain what “systematic” means and implicitly distinguish such studies from other approaches to literature review.

Most engineers and engineering educators are more familiar with a different kind of literature review: narrative review. Narrative review is meant to provide an overview of a given field and is written by a recognized expert in that field. Compared to a systematic literature review, the main differences lie in the areas of problem definition and methodology. Table 1 is adapted from the field of evidence-based medicine [9] and it summarizes the main differences between the two review approaches.

Table 1. Summary of main differences between systematic literature reviews and narrative reviews.

Systematic Literature Review	Narrative Review
Investigates a clearly defined research question.	Provides an overview of a research area
Literature is gathered using explicit and systematic search protocols.	Explicit, systematic literature search protocol is not used.
Studies are selected using a protocol that specifies inclusion and exclusion criteria.	Inclusion and exclusion protocol and criteria are not specified.
Data from primary study may be synthesized in a meta-analysis. Strength of evidence is assessed for individual studies.	Strength of evidence may be assessed for individual studies.
When evidence is lacking, the authors usually recommend further research.	When evidence is lacking, the authors make recommendations based on their opinions and experience.

Systematic literature reviews can be used to advance a given research field. For example, Borego et al. [10] argued that the field of engineering education research would benefit from more SLR reports. They also

provided a very useful and detailed explanation of methodology for proper application of SLR in engineering education research and pointed out that "... narrative reviews differ from systematic reviews in that the identification and selection criteria for sources are usually implicit; narrative reviews typically do not include methods sections" [10]. Therefore, usefulness of SLR as a research tool is well established but its application in engineering fields appears to be lagging behind other fields, such as medicine. Attempts to establish SLR as pedagogical tool are more recent and are discussed next.

2.1. SLR as Pedagogical Tool in Engineering

There are not very many reports of SLR use as a pedagogical tool in engineering education and it seems that it was first used in this fashion in the software engineering area. The most recent report in [11] discussed development of *iterative* SLR (iSLR) and its educational benefits, while an earlier study [12] described successfully teaching undergraduate students some software engineering skills and concepts. One attractive feature of iSLR process is that it is flexible and allows for refinement of results at various stages in the process. This flexibility makes it suitable for novices in a given area of study because their understanding of the problem and process improves as they perform SLR. Studies in [11] and [12] have established that iSLR can successfully be performed by area novices. In our pilot study we followed procedures discussed in [11] with a few modifications, as discussed below.

There are eight stages in the iSLR process [11] as shown in Figure 1.

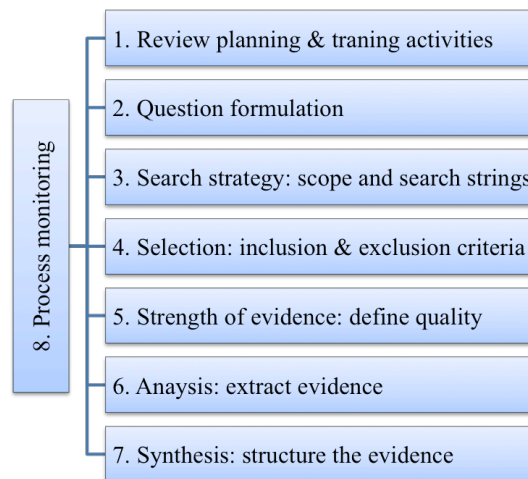


Figure 1. Stages in systematic literature review process.

The usual SLR practice is modified in iSLR by allowing iterations between different stages. For example, finding too many references during the initial search (stage 3.) may indicate that the question (stage 2.) was defined too broadly and needs to be modified. One modification that we introduced deals with the *Search strategy* stage. Instead of letting students come up with search strings right away, we provide them with one seed article that they use for forward and backward *snowballing*, i.e., looking up references cited in that article and looking up papers citing that article. In this way students can gain better understanding of the context of the problem, learn the conventions and language of the specific sub-area, examine keywords used in the article etc. This eases them into the heart of the problem and helps them formulate the initial question.

3. Implementing iSLR

Our first implementation of iSLR was done in a Solid-State Electronics I graduate course, which is taken by MS and PhD electrical engineering students. The course covers many common solid-state physics topics such as band theory of semiconductors, conduction in metals and semiconductors, and carrier transport in classical and semi-classical approaches. Within this course, students undertook experimental characterization of very thin metal films using THz Time-Domain-Spectroscopy (TDS) methods as a research project. This naturally led to an iSLR project related to literature on the topic of "TDS characterization of thin metal films." A total of seven students took the course in the Fall 2014 quarter, and they were divided into three teams (2+2+3). Each team was given a different starting paper. Initial results from this implementation have been reported in [13].

In Winter 2015 quarter, we ran another version of iSLR in Microwave Circuits Design I course which has a follow-on 2nd part in Spring quarter. Both undergraduate seniors as well as graduate students take this course but

at this time only graduate students are required to undertake iSLR. During the first 10-week long quarter we cover passive microwave devices while in the second quarter we discuss microwave amplifiers and other active circuits. In this course we approached the iSLR assignment differently: a) students were allowed to choose their own topic, and b) there was no experimental component that related directly to the topics students selected. This approach makes it more difficult to directly integrate the content of the iSLR project into the course but it retains all the other educational benefits and better motivation stemming from students' choice of their own topic. A total of 11 students were divided into four groups (2+2+3+4).

In both courses each team was set up as an online group in Zotero [14] so that students could share papers they found and do the sorting using directories and annotation features provided by Zotero. This made collaboration on paper search and selection very easy and transparent. For example, each student can have their own directory with papers assigned to them for further reading and within that directory they can further sort papers according to specified selection and quality criteria. Tags and keywords associated with each paper can be used to further group papers once the core idea and subtopics are established. One very useful feature of Zotero is the ability to pull bibliographic information and paper directly from database webpage. This greatly speeds up the search process and students quickly master it.

In order to define a weekly schedule, each stage in iSLR is broken down into a more detailed list of specific tasks, e.g., for items 3. *Search strategy* and 4. *Selection process* we have:

- a) Perform snowballing search from the starting paper and deliver
 - a. Raw list of references, (this should be exported from Zotero in some electronic format for future inclusion in written documents)
 - b. Selection criteria for eliminating / keeping papers from that list
 - c. List of references after selection; each eliminated paper should have a comment or code explaining why it was eliminated.
 - d. Suggestions for possible refinement of research question
- b) Perform database literature search based on keywords and deliver:
 - a. Raw list of all papers
 - b. Selection criteria for eliminating / keeping papers from that list (can be the same as the one used for snowballing)
 - c. List of references after selection; each eliminated paper should have a comment or code explaining why it was eliminated.
 - d. Suggestions for possible refinement of research question
- c) Combine references from a) and b) into a single list

Underlined tasks indicate opportunities for iterative improvement of the research question – the “i” in iSLR. Based on this list a weekly schedule specifying tasks and deliverables was developed. For example, in a 15-week schedule students are given the following tasks in weeks 5 - 7:

Week 5:

- Do a selection of all the acquired papers based on stated criteria
 - o Separate papers on Zotero into directories – one for further reading and one for rejected papers
 - o Submit on D2L a list of papers you: a) examined, b) accepted and c) eliminated

Week 6:

- As group, divide the references from snowballing and continue working on selection and annotation
- Revisit selection criteria now that you have collected more papers
- As a group, produce a draft annotated list from snowballing
- After you have watched librarian's presentation
 - o Decide as a group which search string you will use
 - o Perform database searches and explain why you used certain databases and not others
 - o Store papers in Zotero for further processing

Week 7:

- Finalize the problem statement (last chance to refine it)
- Divide the list of papers from database search among group members
- Perform selection (use titles, keywords and abstracts)
- Annotate and code (“tag”) papers as selection is done
- Assignment for next week:
 - o Report the total number of papers found and number of eliminated ones
 - o Produce a diagram explaining the core idea or concept and how it is divided into sub-topics.
 - o List themes that you observed, if applicable.
 - o Report on how you are doing coding, i.e. which tags are used.

The end of week 7 is roughly where the first part of iSLR is finished and it coincides with the end of first quarter in a two-quarter course sequence. Students are required to produce an interim report consisting of these sections: Summary, Introduction, Division of Labor and Zotero Use, Research Question, Snowballing Results, Database Search Setup, Selection Process and Annotated Bibliography. Total length should be from three to four pages, excluding the bibliography. This breakpoint and interim report would also be recommended for a semester long course but is difficult to fully implement in a single 10-week long course.

4. Assessment

In order to gauge effectiveness of SLR projects as educational tool, we assessed several items:

- a) Student self-efficacy in doing literature reviews before and after iSLR project
- b) Quality of iSLR reports
- c) Identifying major problems or roadblocks to successful implementation of iSLR

Pre-course survey was done at the beginning of the course to establish students' familiarity with any type of literature review process. As Table 2 shows, 13 out of 16 students have done literature review of any kind only once or never. Even lower numbers are reported for literature reviews in technical fields, i.e. sciences and engineering. However, results in Table 3 seem to indicate that students are reasonably confident in their ability to do literature reviews. For example, 12 out of 16 selected strongly agree, agree or are neutral when asked how confident they are they can do a literature review on their own (item 3.). This seems at odds with students' lack of experience in doing literature reviews. We believe that these results indicate poor familiarity with literature review. Conversations with other faculty provide anecdotal support for this observation, i.e., that students are generally unprepared to perform literature reviews. Table 3 also indicates that almost all students believe this skill will be valuable in their education or work.

Table 2. Students' frequency of use of literature reviews prior to SLR project. Both courses included

	Never	Once	Twice	3 or more
Literature reviews done in any field	6	7	1	2
Literature reviews done in technical fields	8	5		2

Table 3. Student self-efficacy for ability to do literature reviews, pre-SLR project. Both courses included.

	Str. Agree	Agree	Neutral	Disagree	Str. Disagree	Not Appl.
1. I am familiar with literature review process		5	4	2	5	
2. I can explain various stages in literature review		2	3	6	5	
3. I am confident that I can do a literature review on my own	2	3	7	2	2	
4. Learning how to do literature review will be valuable in my studies	5	10			1	
5. Learning how to do literature review will be valuable in my current workplace	3	9	2			2

In another report [13] we analyzed changes in student self-efficacy by comparing pre- and post-project survey results but only from one course. Early indications are that student self-efficacy improves after SLR project but their judgment of usefulness of SLR declines. We also found that the *Selection* stage was the most time consuming while *Question formulation* was the most confusing. Finally, *Synthesis* stage needed to be explained much better in class.

4.1. SLR report assessment rubric

Rubrics are widely used and there are many books and other resources devoted to their development, e.g. [15]. In our other courses we have found rubrics to be very helpful in grading. In addition, they lead to better and more consistently assessment of the quality of submitted reports and provide more useful feedback to students, especially if they are included as part of the assignment. At first, we adapted an existing rubric, which was developed for assessment of general literature reviews [16]. Among the three reports in ECE 511, one was assessed to be between Developed and Exemplary, one was Developed and one in between Average and Developed. This was deemed to be a very good performance for a pilot study. However, it quickly became

apparent that this rubric needed to be substantially revised to address items related to iSLR process and to make it more applicable to the type of writing usually done in technical reports.

Tables 4 and 5 present our first attempt at designing an iSLR report rubric. It is split in two parts because the project runs across two quarters and interim report is required. At this stage students have finished the *Selection* stage which enables them to write an annotated bibliography. Therefore, the first part is very specific in terms of requirements and the way they are assessed. This should help students write good reports even without initial drafts. This expectation was confirmed in our first application of it during winter 2015 quarter when all of the submitted reports met or exceeded expectations. However, the second part is more challenging both in terms of critical thinking required as well as writing. This is reflected in the criteria and performance levels listed in Table 5 which are less specific and rely more on evaluator's experience and judgment. Nonetheless, they cover areas that we have found useful in assessing previous set of reports. As of this writing, we do not have the results from the second course – those will be presented at the conference.

Table 4. Systematic literature review report rubric - part 1.

Criteria	Does not meet expectations	Approaches expectations	Meets expectations	Exceeds expectations
Format	Does not follow specs	Follows specs but sloppy	Follows all specs; has all the required parts	
SLR process	Procedures not followed and misunderstood	Procedures followed but some parts misunderstood	Procedures followed	Complete and detailed understanding of SLR demonstrated
Research question	1. Trivial question with little thought put into it 2. No evidence of revision	1. Acceptable question but poorly posed 2. Some evidence of revision	1. Relevant and clear question 2. Clear evidence of revisions	Original way to pose a question that shows deep understanding of the field
Selection	1. Arbitrary selection 2. No clear criteria given 3. No evidence of use of criteria	1. Few criteria given but some are unclear 2. Some evidence of use of criteria	Clear and relevant selection criteria given and utilized	Novel and unexpected ways of defining criteria and applying them
Annotated Bibliography	1. Does not follow IEEE format 2. Number of papers is too big or too small 3. No annotation or it does not make sense	1. Follows IEEE format 2. Number of papers is reasonable 3. Most annotations are sensible	1. Follows IEEE format 2. Reasonable number of papers 3. Clear and sensible annotations	Detailed annotations that would enable a serious research project in a given area

5. Conclusions

Our pilot study was limited in scope and it aimed to replicate some earlier findings and to demonstrate that:

- iSLR is a very promising methodology that provides a framework for teaching students **both** the methodology of systematic literatures reviews as well as material relevant to the course in question
- Implementation is not onerous
- Students benefit from performing iSLR.

We have implemented it in two graduate-level courses along with detailed schedule of tasks, requirements and assessment rubrics. Initial results indicate good student performance and improvements in self-efficacy but we have yet to collect all the data. The study is limited by the relatively small number of students involved and will have to be expanded to other courses, instructors, departments and institutions. We hope that more instructors will decide to experiment and implement the methodology presented here and we would welcome collaboration on its future development.

Table 5. Systematic literature review report rubric - part 2.

Criteria	Does not meet expectations	Approaches expectations	Meets expectations	Exceeds expectations
Report outline (Abstract, Introduction, Methods, Results, Synthesis, Annotated bibliography)	1. Significant sections of the report are missing	1. Most sections of the report are present 2. Distinction between sections or their content is not appropriate	1. All sections are present and have appropriate content	
Organization (research question, core idea, subtopics)	1. Research question and core idea not established 2. Subtopics either not present, too specific, too broad or not appropriate	1. Research question and core idea vaguely described 2. Subtopics present but do not follow logical sequence or are inappropriate	1. Research question and core idea clearly outlined 2. Most subtopics are appropriate and follow logical sequence	1. Research question and core idea clearly outlined 2. All of the literature discussion organized into appropriate subtopics, which follow logical sequence
Literature analysis (strength of evidence, relevance and importance, systematic application)	1. Quality criteria not defined. 2. Relevance and importance of individual studies not discussed. 3. Relationship among studies not discussed. 4. Analysis not applied systematically.	1. Quality criteria defined but not applied consistently. 2. Relevance or importance of some individual studies partially established. 3. Relationship among studies cursorily examined. 4. Systematically applied to small segment of the literature.	1. Quality criteria defined but not applied consistently. 2. Relevance and importance of most studies partially established. 3. Relationship among studies partially established. 4. Systematically applied to most of the literature.	1. All of the components fully satisfied, clearly explained and supported by the discussion of the literature.
Contribution and rationale	1. Contribution of current review not stated. 2. Stated rationale is unclear or follows poor logic.	1. Contribution stated but not clearly. 2. Rationale stated but not supported by discussion of the literature.	1. Contribution clearly stated but not fully supported by the literature. 2. Rationale stated and marginally supported by discussion of the literature.	1. Clear, logical explanations for contribution and rationale established. 2. Contributions and rationale are supported by the literature.
Clarity of writing	1. Writing style not appropriate for literature review. 2. Frequent grammatical and spelling errors. 3. Inconsistent voice.	1. Writing style is appropriate but occasionally unclear. 2. Occasional grammatical or spelling errors. 3. Inconsistent voice.	1. Writing is appropriate, clear and free of grammatical and spelling errors, and expresses single voice.	1. Writing is appropriate, clear and free of grammatical and spelling errors, and expresses single voice. 2. Writing style enhances the impact of the conclusions.
Overall quality	1. Report has a feel of a rush job with as little effort as possible put into it. 2. Many little problems and a few big ones.	1. OK overall quality that students would not be ashamed to share with their parents.	1. Excellent quality so that students would want to include it in their portfolio of projects to show potential employers.	1. Publication quality.

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