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Understanding Undergraduate Engineering Student Information Access and Needs: Results from a Scoping Review

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Abstract

To the authors knowledge this is the first review to examine the current body of research on how engineering students access, use, and understand information; identify gaps in the literature, and how this can be used to support information literacy education in the engineering disciplines. Engineering students are required to create, problem solve, and improve, using engineering principles to develop their skills in technical, environmental, socioeconomic and political aspects of the engineering process. They are increasingly faced with the availability of rapidly shifting information types, which are gathered from sources like Google and Reddit. Finding and interpreting such information, even when found correctly through sources outside traditional research boundaries (technical documents found online vs. peer review articles through a library catalog), creates a disconnect between students and the desire of librarians or faculty to teach traditional research and information seeking skills.

A scoping review was conducted using the Arksey and O'Malley modified framework. Six databases focusing on information, education, and engineering research were searched (LISA, ERIC full-text, ASEE, ScienceDirect, EducationSource, and Scopus). Papers were included if they addressed engineering student information seeking behaviors or needs. Studies that focused on social science or humanities students were excluded. The data were examined to find methodological trends, research areas, gaps in knowledge, and key findings. This review included 44 articles in the final review. Analysis grouped research into four emerging themes: Student information behavior mirrors that of professionals; Design thinking as a guiding force for information behavior; Design work requires the use of a specialized information sources; Methodological and Theoretical approaches.

Results demonstrate a significant gap in knowledge around information seeking behavior specific to engineering students. Research into this area should be developed to be more inclusive and diverse, which will help increase recruitment and support of underrepresented groups, and overall will improve student success in engineering. Additional research should be conducted to validate or confirm previous findings, build on existing assessment protocols, develop new protocols and methodologies, and explore the application of new theoretical frameworks. There should be a focus in engaging cross-disciplinary stakeholders in the research process.

Introduction

Engineering education places a growing emphasis on design and capstone-based projects founded in a students' ability to effectively seek, understand, and apply information. Engineering students are required to create, problem solve, and improve, using engineering principles to develop their skills in technical, environmental, socioeconomic and political aspects of the engineering design process. Engineering students are increasingly not taking a traditional scientific approach to research, mirroring professional engineers and scientists [1]. Henry Petroski stated that "Science is about knowing, engineering is about doing." [2] In undergraduate education this is reflected in the approach to courses and research in engineering education, to the point it can be referred to as the 'design process' rather than the 'research process.' Engineering practitioners find and use a variety of academic and technical information sources in their work and as early as their 1st year, when engineering students, by nature of their chosen path, deviate from their peers in their information seeking behavior.

There is a well-established body of literature around the information seeking behaviors of professional engineers. Professional engineers need to find highly reliable, and deeply technical information to successfully make critical decisions [3]. Allard, Levine, & Tenopir identify that professional engineers rely more heavily on colleagues, their personal collections, or to search engines such as Google to find information [4]. Engineers may rely increasingly on tools like Google, as well as discussions with colleagues as the most important factor identified by Fidel and Green [5], and Anderson et al. [6] is accessibility. It is estimated that practicing engineers may spend one third of their work time finding, managing, and using information [7]. This makes practicing engineers and, subsequently, engineering students' distinct and unique user groups from individuals in other fields of study and occupations. While the importance of tailoring information seeking instruction to the user group is relatively established in research looking at information seeking in disciplines ranging from the humanities to nursing, there are not currently any equivalent comprehensive reviews considering these behaviors in the engineering fields[8]–[11].

In line with information behavior patterns of professional engineers, we see engineering students are similarly sharing information informally in their design classes [12]. The acknowledgement of this leads into the deeper question of where is this original information coming from, and how the information is initially found. By focusing on sharing information without having the background of where the information originally comes from there is foundationally missing knowledge relevant to understanding how to teach engineering students how, and where to search. Similarly, Taraban focuses on the study behaviors of engineering students [13]. While he identifies a significant jump in reading strategies, the focus on text rather than where the student find the text leaves the gap in knowledge. This study does identify that it is difficult to break the students out of a 'transmission-of-knowledge' mindset, of which the question of how to do so runs parallel to our question of where are they getting the information in the first place.

For information literacy efforts to be effective with engineering students, they must reflect the standards and expectations within the engineering profession around information seeking behaviors and take into consideration the variety of sources and ways in which practicing engineers interact with information. Reviewing methods of information literacy instruction for undergraduate engineering students, Phillips et al. conducted a systematic review to identify the most effective methods of undergraduate information literacy instruction [14], [15]. Findings of the review concluded that much of the research in this area focuses on student self-report data and is not methodologically rigorous. While understanding effective approaches to information literacy instruction for engineering students is important for educators, efforts in this area would be significantly aided by a more comprehensive understanding of student information behavior to better inform the content and, ultimately, the approach required for effective instruction.

The uniqueness is not currently reflected in much of the existing literature about information seeking behavior and critical appraisal skills of undergraduate engineering students. Scoping reviews, as defined by Arksey and O'Malley [16], summarize a range of evidence to convey the breadth and depth of evidence, and differ from systematic reviews in that they do not typically quantify the effect of interventions. By examining the range, nature, characteristics, and extent of the current research, and summarizing the existing evidence, our goal is to provide a foundation to better understand this area of undergraduate engineering education, a field that is increasingly interdisciplinary. Research into information seeking behaviors has historically been focused on undergraduate students broadly, without attention paid to disciplinary norms and expectations, or more specifically on those students studying in the social sciences or humanities.

Developing a stronger understanding of how undergraduate engineering students seek, access, and use information is closely linked to the evolution of engineering curricula. Undergraduate engineering programs have integrated design work throughout the curriculum [17] and accrediting bodies such as Accreditation Board for Engineering and Technology (ABET) and the Canadian Engineering Accreditation Board (CEAB) are placing increased emphasis on information literacy and how it is correlated with life-long learning [18], [19]. Ercegovac [20] has identified a paucity of research about the information behavior of engineering undergraduate students. This paper begins to explore the question, "What are the information behaviors of undergraduate engineering students?" By identifying emerging themes in existing research, it will highlight existing gaps in the literature providing a foundation on which to guide future research.

Scoping Review

Scoping reviews and their methodology are rooted in the health sciences where they are used to rapidly map the existing literature and identify research gaps. They are increasingly being used outside of traditional health contexts to map existing literature on a particular topic where they have been used to generate research questions and topics, identify gaps in the literature, and summarize and disseminate knowledge on a research area. Using Mays et al. definition:

> *"[scoping studies] aim to map rapidly the key concepts underpinning a research area and the main sources and types of evidence available, and can be undertaken as stand-alone*

projects in their own right, especially where an area is complex or has not been reviewed comprehensively before." [21]

This methodology has demonstrated its value when investigating topics or research areas where evidence takes a variety of forms thereby making other knowledge synthesis methodologies, like systematic reviews, inappropriate and where a non-systematic literature review may lack the rigor to make actionable or credible assertions [16].

In comparison to other approaches to mapping literature, most notably systematic reviews and meta-analysis, scoping reviews stand apart as a distinct methodology. In comparison to systematic reviews, the research questions considered in scoping reviews can be more broadly defined and criteria used to determine inclusion and exclusion in the study is developed during the review phase [16]. There is also an emphasis on including a wider variety of information types than in a systematic review where the types of studies designated for inclusion are defined before the searches are run. Rather than a detailed synthesis and appraisal of information as per systematic reviews, scoping reviews focus on providing a narrative account of the literature. Scoping reviews frequently present collected and included data in the form of tables and charts to supplement any narrative analysis and to more easily identify and surface patterns in the information that aid understanding and support future inquiry in the area of review [16], [22].

This review followed the five-stage model developed by Arksey and O'Malley [16]: scoping, search, screening, data extraction and data analysis and are reporting according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) Checklist [23].

Scoping

To become familiar with the existing literature on this topic a preliminary search was conducted in LISA to identify papers and reviews that included anything on identifying the information seeking behaviors of undergraduate engineering students, initially including information behaviors of undergraduate students in Science, Technology, Engineering, and Math (STEM) fields. Developing a search strategy was a complex process that required balancing the need to be as comprehensive as possible with limiting the noise inherent in a search that includes such wide reaching terminology such as "education" "undergraduate engineering" and "information seeking". Information was collected on population, demographics, country of origin, sample size, engineering discipline, communications, experiences, theories, models, and dates.

Search

A comprehensive search strategy was built for each database by a practicing engineering and instructional design librarian. The SPIDER (Sample, Phenomenon of Interest, Design, Evaluation, Research type) search strategy was used, which is a qualitative and mixed methods alternative search [24]. LISA (Proquest), ERIC full-text (Proquest), American Society for Engineering Education PEER (ASEE), ScienceDirect (Elsevier), EducationSource (Ebsco), and Scopus (Elsevier) were searched for relevant peer reviewed sources. We followed this up by searching relevant articles reference lists and by hand searching ASEE proceedings for applicable studies outside of the coverage provided in the identified databases. A wide variety of publications were included as practicing engineers have a tradition of publish significantly in conference proceedings and through professional organizations. English language studies were the only limitations placed on our initial scoping searches. Initial searches were conducted between September 7, 2018 and October 30, 2018 with additional searches conducted between February 25, 2019 and March 7, 2019.

The key search terms used to identify relevant research were based on our research question of: “What are the information behaviors of undergraduate engineering students?” We identified “engineer”, “undergraduate”, and “information behavior” as foundation key words. From this we developed a list of search terms including:

“information literacy”, “information use”, “information need” “information behavior” “education” “engineering education”

Sample search from LISA: ("engineering education") AND "undergraduate" AND (information AND (literacy OR use OR Need OR behavior OR access))

In supplemental searching, conducted in response to stakeholder consultation, search strings were enhanced and used during the additional searching phase to better capture the complexity of the topic and variety of ways in which it might be described across databases.

A comparative sample search from LISA: (Information w/1 (behavior or behaviour or literacy or need* or design or seek* or gather* or manag*)) AND (Undergraduate OR post-secondary OR senior OR junior OR sophomore OR freshman OR college OR University OR “first-year” OR “first year”) AND (Engineer* OR (Engineer* w/1 student*)

Screening

Studies found through the search were imputed into Covidence, a review management tool, during the first phase of screening. Where possible, search results were downloaded in RIS form to the researcher’s computer and then uploaded to Covidence. Titles and abstracts were then screened by JAS for relevance according to the eligibility criteria. In instances where .RIS files were not available such as ASEE PEER, title and abstract screening was conducted on the search platform and relevant articles tracked separately.

Studies were eligible for inclusion if they were related to undergraduate engineering information literacy or information gathering. The studies could be qualitative (interviews, case studies, focus groups), quantitative studies (questionnaires, before/after studies, cohort studies, case control, or randomized control trials), or mixed methods in nature. Relevant review articles would as well be eligible for inclusion.

Once identified through initial title and abstract screening, efforts were made to obtain copies of all identified articles for full title review. Attempts to obtain papers that were not available through the databases were made through interlibrary loan requests, and contacting authors. In the second stage of screening, full text articles were reviewed by JAS, KW, and KM on the researchers' desktop for further examination and to determine eligibility in with results tracked in Covidence. During the second phase of screening, a number of identified articles that met the basic eligibility criteria were excluded because the content focused on assessing teaching interventions, determining awareness of library services, or that more broadly investigated science, technology, engineering, and math (STEM) students without distinguishing engineering students as a distinct population in results reporting.

Data Synthesis

A standardized form was used to extract data from selected studies (JAS), which were verified for accuracy by KM and KW. The following data were recorded: lead author, year of publication, location, participants, methods, analysis, research setting, outcomes. The literature was categorized according to methodological trends, key findings, and research setting. The guiding question was "What are the information behaviors of undergraduate engineering students?" The authors were open to adding categories as necessary. The study topics were then compared to find similarities and themes, which were then clustered into broader categories. Gaps and key findings were identified after data analysis in Results.

Results

This review identified 1854 total studies, 326 duplicates were identified by the Covidence platform, leaving 1528 studies for title and abstract screening. Title and abstract screening produced 138 studies for full-text review. 2 additional duplicates were identified in the full-text review stage, 9 were unavailable in full-text, 9 studies were not about undergraduate engineering students, 13 titles were not studies but book reviews or other irrelevant publication types, and 72 studies concerned outcomes irrelevant to this scoping review. From full-text screening 33 works were identified as relevant. Hand searching during the full-text review process and the consultation stage resulted in an additional 11 additional titles to be abstracted. A total of 44 works to were analyzed in this review. (Figure 1, Table 1).

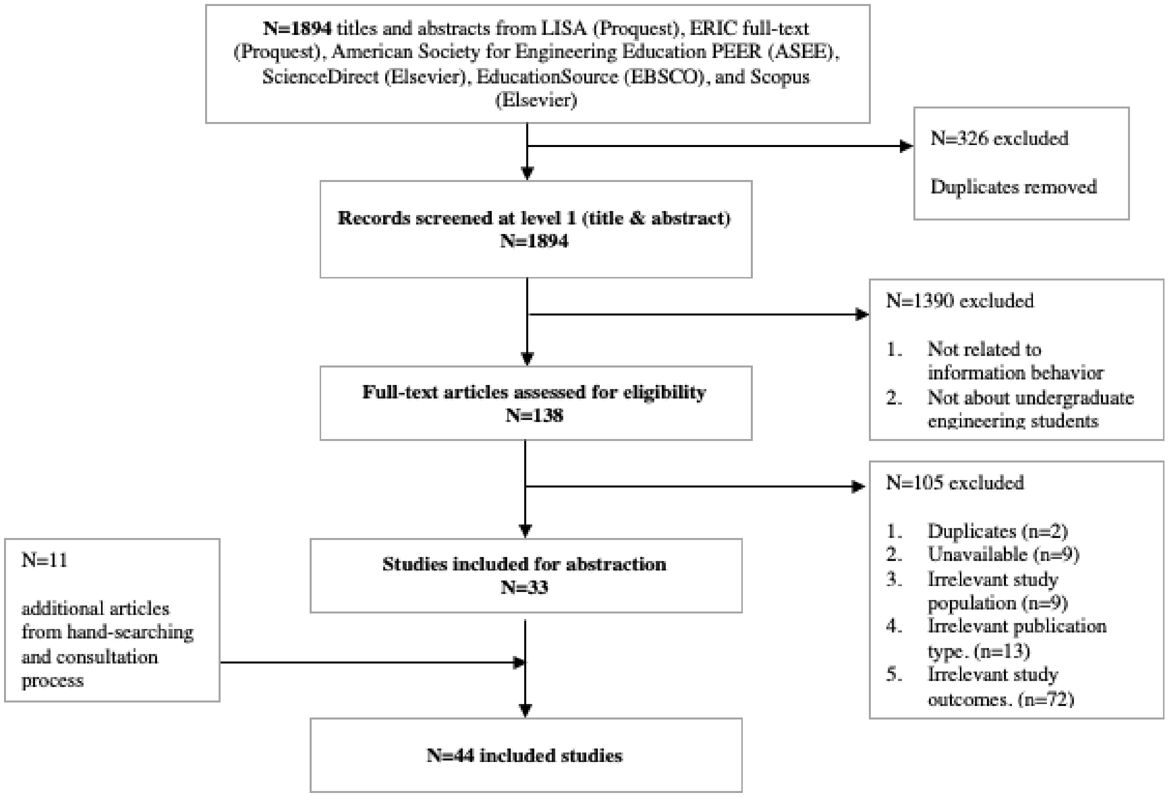

Figure 1. PRISMA-SR Flowchart

Table 1: List of studies included in scoping review

Author	Year	Country	Setting	Sample Size	Objective	Published after ACRL rescinded ILCSHE	Theory (of Information Behavior)
Al-Bustan & Etedali [25]	2007	Kuwait	Mandatory English-language, for credit research-writing course.	144	Establish the information-seeking patterns of students		Wilson (1981)
Andrews & Patil [26]	2007	Australia	A first-year first semester course focusing professional practice and develops communication, teamwork and problem-solving skills.	53	Evaluate and reflect on the effectiveness of IL instruction		ANZIIL (2004)
Atman et al. (1) [27]	1999	United States of America	A series of lab-based studies.	26 1st 24 4th	In-depth study of engineering student approaches to open-ended design problems.		n/a
Atman et al. (2) [28]	2005	United States of America	A series of lab-based studies.	32 1st 61 4th	In-depth study of engineering student approaches to open-ended design problems.		n/a

Atman et al. (3) [29]	2007	United States of America	A series of lab-based studies.	26 1st 24 4th 19 Experts	In-depth study of engineering student approaches to open-ended design problems.		n/a
Baer & Li [30]	2009	United States of America	Campus-wide email survey.	216	Understanding use of the library as a place and the use of information resources regardless of location.		Hemminger et al. study
Barsky et al. [31]	2011	Canada	A 2nd year course with a focus on engineering practice and technology in an international context through Problem-Oriented Learning.	64	Investigates information sources used by engineering students to address authentic socio-technical problems.		n/a
Cribb & Woodall [32]	1997	Australia	A mandatory first-year course centered on engineering practice.	500	Examining the impact of web-based technology for IL instruction.		n/a
Denick et al. [33]	2010	United States of America	A mandatory first-year, first term Expository Writing and Reading Course.	135	Determine the FYE design students' information literacy skills, validate citation analysis, and refine instruction.		
Ercegovac [20]	2009	United States of America	A second-year course focusing on fundamental computer science concepts.	70	Examine students' content knowledge on core information literacy performance indicators and outcome measures as described by ACRL STS.		ACRL IL SET
Fosmire (1) [34]	2012	United States of America	n/a	n/a	Explaining the information resources and processes required by engineers engaged in the design process and combining engineering education and library science literature.		ISP Kulthau (2004)
Fosmire (2) [35]	2017	United States of America	n/a	n/a	Explaining how critical information literacy provides a structure for determining information needs and use during the design process; how it helps designers produce holistic solutions that question the assumptions implicit in the information they gather.	✓	Critical Information Literacy & ACRL ILF
Fosmire et al. [36]	2015	United States of America	A competency-based degree plan with information literacy embedded in the outcomes.	23	Comparing student outcomes for competency-based and traditional classroom approaches to information literacy instruction.		CRAAP/Open Badge System Framework
Gadd et al. [37]	2010	United Kingdom	Undergraduate Construction Engineering Management courses	23	Understand the information literacy skills of students and what components need to be addressed to		n/a

					improve overall quality of citations behaviors.		
Hanlan et al [38]	2014	United States of America	An undergraduate introductory-level mechanical engineering design course.	27	Establish what effect librarian-led IL instruction may have on solutions to engineering design challenges.		n/a
Hanlan & Riley [39]	2015	United States of America	A third-year project-based course taking place at a variety of international project centres.	n/a	How librarians teach students about information seeking and lifelong learning and what information sources students use.		Information Rich Engineering Design (IRED) and ACRL ILF
Holland et al. [40]	1991	United States of America	A four stage research collaboration between Indiana University and NASA	640	What are the information sources being used and how, how does print and electronic use differ, the role of technology, and determine the effect of instruction.		ABET
Jeffryes & Lafferty [41]	2012	United States of America	Students participating in a co-operative education program as part of their degree.	36	Understanding co-op students' on-the-job information usage, degree of comfort with engineering literature, and experiences learning to use engineering resources.		n/a
Johri et al. [42]	2014	United States of America	An email survey of all 1st year engineering students.	204	Understanding of digital media and information use by engineering students.		Ecological Perspective
Jones [43]	2017	United States of America	Formula SAE (FSAE) teams, an automotive racing project sponsored by the Society for Automotive Engineers.	42	How student engineering problem-based learning teams engage information challenges as they build sustained knowledge-based organizations.	✓	Cultural-Historical Activity Theory
Kerins et al. [44]	2004	Ireland	Information Behavior and Knowledge Management in Project-Based Learning (PBL*) Engineering Teams	14	What are the information seeking behaviors of students studying to become professionals.		Leckie et al.'s
Leachman & Leachman [45]	2016	United States of America	A third-year mechanical engineering systems design course.	n/a	Modifying the Quality Function Deployment (QFD) engineering design method to monitor and assess information resources as a natural outcome of the design process.		ACRL ILF
Leckie & Fullerton [46]	1999	Canada	Two large Canadian universities.	233	Exploring what science and engineering faculty doing with respect to the development of information literacy in their undergraduate students.		n/a

MacAlpine [47]	2005	United States of America	The first design course in a multi-disciplinary engineering curriculum.	50	Understanding the effect of active learning approaches to information literacy.		n/a
Maddison et al. [48]	2014	Canada	A fourth-year discipline-specific engineering course.	13	Understanding the effect of flipped classroom technique to information literacy and prepare students for the workplace.		n/a
Maddison [49]	2015	Canada	Second and fourth year discipline specific courses of varying sizes.	227	Understanding the effect of flipped classroom technique to information literacy in different sized classrooms.		n/a
Majid & Tan [50]	2002	Singapore	A questionnaire distributed to computer engineering students.	102	Investigation of the information needs and information seeking behaviour of undergraduate computer engineering students.		Shanmuganthan 1999 and Yang 1998
Masters et al. [12]	2008	United States of America	Lab-based studies.	367	Comparing design learning and information use between years of engineering education.		I-Beam Design Learning Model
Olakanmi et al. [51]	2016	Botswana	A first-year, first semester Introduction to Engineering course.	10	Evaluate first-year engineering students' conceptualisation of design problems in comparison to graduate students.		ABET
Palmer & Tucker [52]	2004	Australia	Instruction deployed throughout the first semester of first-year on- and off-line.	66	Evaluate and reflect on the effectiveness of IL instruction		n/a
Phillips & Zwicky (2) [53]	2017	United States of America	Embedded librarians in an elective, project-based design course.	22	Understanding the use of patent information in engineering design.	✓	n/a
Phillips & Zwicky (1) [54]	2018	United States of America	An undergraduate mechanical engineering technology design course.	84	Does IL instruction result in increased undergraduate engineering technology student IL learning and self-efficacy	✓	ABET
Purzer et al. [55]	2014	United States of America	n/a	n/a	The development of two valid and reliable IL assessments.		ABET

Ramaiah & Shimray [56]	2018	India	An in-person survey of patrons of the institutions engineering library.	300	Evaluate the use of various library services and facilities by students.	✓	n/a
Saleh [18]	2011	Canada	A web-based survey deployed near the end of the academic year following a project that took 8 months project for a final year capstone design course.	42	Investigates the collaborative information behavior of undergraduate engineering students working on a course-based engineering project.		n/a
Saleh & Large [57]	2011	Canada	A web-based survey deployed near the end of the academic year following a project that took 8 months project for a final year capstone design course.	42	Investigates the collaborative information behavior of undergraduate engineering students working on a course-based engineering project.		n/a
Scharf [58]	2014	United States of America	A technical writing course for upper-year students.	274	Measuring the effectiveness of a brief diagnostic essay as an assignment and as a pre- and posttest to measure information literacy skills.		ACRL IL SET
Van Epps & Sapp Nelson [59]	2013	United States of America	A Fundamentals of Speech Communication course that focuses on oral communication skills for students in all disciplines.	36	Examining influence of the timing of library instruction to the type and quality of resources students use.		n/a
Walton & Archer [60]	2004	South Africa	The web literacy section of an academic literacy course.	n/a	To document, evaluate and reflect on students' use of evaluative frameworks.		Critical Action Research
Wertz et al. (1) [61]	2011	United States of America	An introductory FYE course students were assigned a group design project.	n/a	Reporting the development of an instrument used to assess skills related to information gathering in first-year engineering students.		Kulthau's ISP and ABET
Wertz et al. (2) [62]	2013	United States of America	A large-enrollment required first-year engineering course focusing on the engineering discipline and design principles.	n/a	Understanding the extent to which students gather information from a variety of sources and from high-quality sources, use gathered information to support an argument, and document information sources.		Kulthau's ISP and SCONUL
Zabihian et al. [63]	2015	United States of America	A 4th year, 2-term mechanical engineering system design course.	n/a	Determine the effect of embedded librarian IL instruction on information literacy skills.		ACRL IL SET
Zhao & Mawhinney [64]	2014	Canada	A large-enrollment required general communications course for engineers.	17	Investigating the challenges related to information literacy that Chinese undergraduate students face in		ACRL IL SET and SCONUL

					comparison with English speaking peers when completing a research paper.		

Table 2: Type of assessment used

Author	Year	Survey	Citation analysis	Content Analysis	Mixed Methods	Other
Al-Bustan & Etedali	2007	✓				
Andrews & Patil	2007	✓		✓	✓	
Atman et al. (1)	1999					Verbal Protocol Analysis
Atman et al. (2)	2005					Verbal Protocol Analysis
Atman et al. (3)	2007					Verbal Protocol Analysis
Baer & Li	2009	✓				
Barsky et al.	2011	✓		✓	✓	Interview
Cribb & Woodall	1997				✓	Summative Assessment
Denick et al.	2010		✓			
Ercegovac	2009	✓				
Fosmire (1)	2012					Literature Review
Fosmire (2)	2017					Literature Review
Fosmire et al.	2015		✓			
Gadd et al.	2010		✓			
Hanlan et al	2014	✓	✓		✓	
Hanlan & Riley	2015	✓	✓		✓	
Holland et al.	1991	✓				
Jeffryes & Lafferty	2012	✓				
Johri et al.	2014	✓				
Jones	2017	✓			✓	Interview & Participant Observation
Kerins et al.	2004					Interview
Leachman & Leachman	2016					Case Study
Leckie & Fullerton	1999	✓				
MacAlpine	2005	✓			✓	Research logs
Maddison et al.	2014	✓			✓	Summative Assessment
Maddison	2015	✓				
Majid & Tan	2002	✓				
Masters et al.	2008	✓				
Olakanmi et al.	2016					Ethnographic Participant Observation
Palmer & Tucker	2004	✓				
Phillips & Zwicky (2)	2017			✓		
Phillips & Zwicky (1)	2018	✓				

Purzer et al.	2014					Instrument Development
Ramaiah & Shimray	2018	✓				
Saleh	2011	✓			✓	Interview
Saleh & Large	2011	✓				
Scharf	2014					Scharf Diagnostic Essay Prompt (SDEP)
Van Epps & Sapp Nelson	2013		✓			
Walton & Archer	2004				✓	
Wertz et al. (1)	2011		✓			
Wertz et al. (2)	2013		✓			
Yu et al.	2006		✓			
Zabihian et al.	2015	✓				
Zhao & Mawhinney	2014	✓		✓	✓	Interview

Table 3: Subjects in study

Author	**Year**	**Gender**	**Age**	**Year of Study**	**Type of institution**	**Discipline of Engineering**
Al-Bustan & Etedali	2007	n/a	n/a	Any	Public Comprehensive Research	Any
Andrews & Patil	2007	n/a	n/a	1st	Public Comprehensive Research	First-year (no/any major)
Atman & et al (1)	1999	1st year: 11F and 15 M 4th year: 4 F and 20 M	18.1 and 23.6 years	1st and 4th	Public Comprehensive Research	First-year (no/any major) and Fourth Year
Atman et al. (2)	2005	1st year: 9F and 23 M 4th year: 15 F and 46 M	18.0 and 23.2 years	1st and 4th	Public Comprehensive Research	First-year (no/any major) and Fourth Year
Atman et al. (3)	2007	n/a	18.0 and 24 years	1st and 4th	Public Comprehensive Research	First-year (no/any major) and Fourth Year
Baer & Li	2009	35% F (all groups)	n/a	Any	Institute of Technology	Undergraduate (mechanical and civil), Graduate, and Faculty
Barsky et al.	2011	n/a	n/a	n/a	Public Comprehensive Research	n/a
Cribb & Woodall	1997	n/a	n/a	1st	Public Comprehensive Research	First-year (no/any major)
Denick et al.	2010	n/a	n/a	1st	Public Comprehensive Research	First-year (no/any major)
Ercegovac	2009	n/a	n/a	2nd	Public Comprehensive Research	Computer
Fosmire (1)	2012	n/a	n/a	n/a	Public Comprehensive Research	Any
Fosmire (2)	2017	n/a	n/a	n/a	Public Comprehensive Research	Any
Fosmire et al.	2015	n/a	n/a	n/a	Polytechnic Institute in a Public Comprehensive Research	First-year (no/any major)
Gadd et al.	2010	n/a	n/a	1st and 2nd	Public Comprehensive Research	Civil

Hanlan et al	2014	n/a	n/a	2nd or higher	Polytechnic Institute	Mechanical Engineering
Hanlan & Riley	2015	n/a	n/a	3rd	Polytechnic Institute	Any
Holland et al.	1991	16% F	n/a	3rd and 4th	n/a	Aeronautical/astronautical
Jeffryes & Lafferty	2012	n/a	n/a	All	Public Comprehensive Research	Civil, Computer Science, Electrical, Mechanical, and other (not specified).
Johri et al.	2014	79% M	n/a	1st	Public Comprehensive Research	First-year (no/any major)
Jones	2017	n/a	n/a	All	n/a	Any
Kerins et al.	2004	n/a	n/a	"Final year"	Public Comprehensive Research	Electronic, mechanical, and manufacturing
Leachman & Leachman	2016	n/a	n/a	3rd	Public Comprehensive Research	Mechanical
Leckie & Fullerton	1999	n/a	n/a	n/a	Public Comprehensive Research	Any
MacAlpine	2005	n/a	n/a	1st	Private Liberal Arts	First-year (no/any major)
Maddison et al.	2014	n/a	n/a	4th	Public Comprehensive Research	Geological (mining focus)
Maddison	2015	n/a	n/a	2nd and 4th	Public Comprehensive Research	Civil, Environment, and Geological Engineering
Majid & Tan	2002	62.7% M 37.3% F	n/a	Any	Public Comprehensive Research	Computer
Masters et al.	2008	n/a	n/a	All	Public Comprehensive Research	Civil and Mechanical
Olakanmi et al.	2016	2 F and 8 M	n/a	1st	Public Research specializing in Engineering, Science and Technology	Mechanical, Energy, & Industrial; Civil & Environmental; Electrical, Computer & Telecommunications; Mining & Geological; and Chemical, Metallurgical & Materials
Palmer & Tucker	2004	13.6% F and 86.4% M	20.2	1st	Institute of Technology	First-year (no/any major)
Phillips & Zwicky (2)	2017	20 M, 2 F	n/a	4th	Polytechnic Institute in a Public Comprehensive Research	Mechanical
Phillips & Zwicky (1)	2018	81 M, 3 F	n/a	“upper level”	Polytechnic Institute in a Public Comprehensive Research	Mechanincal Engineering Technology Majors
Purzer et al.	2014	n/a	n/a	n/a	n/a	Any
Ramaiah & Shimray	2018	73.33% M	84.01 % 20-22 years	Any	Public Comprehensive Research	Any
Saleh	2011	n/a	n/a	4th	Public Comprehensive Research	Mechanical, Chemical, Civil, Engineering Physics, and Electrical
Saleh & Large	2011	n/a	n/a	4th	Public Comprehensive Research	Mechanical, Chemical, Civil, Engineering Physics, and Electrical
Scharf	2014	n/a	n/a	3rd or 4th	Institute of Technology	Any
Van Epps & Sapp Nelson	2013	n/a	n/a	1st	Polytechnic Institute in a Public Comprehensive Research	First-year Engineering Students (all)
Walton & Archer	2004	n/a	n/a	1st	Public Comprehensive Research	First-year (no/any major)
Wertz et al. (1)	2011	n/a	n/a	1st	Public Comprehensive Research	First-year (no/any major)
Wertz et al. (2)	2013	n/a	n/a	1st	Public Comprehensive Research	First-year (no/any major)
Yu et al.	2006	n/a	n/a	1st, 2nd, and 4th	Public Comprehensive Research	1st Year (no/any major); 2nd and 4th year Chemical
Zabihian et al.	2015	n/a	n/a	4th	Public Comprehensive Research	Mechanical and aerospace

Zhao & Mawhinney	2014	Male		1st and 2nd	Public Comprehensive Research	Mining and materials, Mechanical, Electrical and Computer, and Civil.

Of the 44 papers included 16 quantitative [12], [20], [25], [30], [40]–[42], [46], [49], [50], [52], [54], [56]–[58], [63]; 14 qualitative [27]–[29], [33], [36], [37], [44], [45], [51], [53], [59], [61], [62], [65]; 11 mixed methods studies [18], [26], [31], [32], [38], [39], [43], [47], [48], [60], [66]; two literature reviews [34], [35]; and one instrument development paper [55]. The included studies were published between 1991 and 2018, having a median age of 5.5 years, and with five of the studies [28], [31], [36], [41], [42] having been published after Association of College and Research Libraries (ACRL)'s Information Literacy Competency Standards for Higher Education (ILCSHE) were rescinded (Table 1).

Papers were primarily published in the United States (n=26) [12], [20], [27]–[30], [33]–[36], [38]–[43], [45], [47], [53]–[55], [58], [59], [61]–[63], the remaining papers were published in Canada (n=7) [12, 25-30], Australia (n=4) [20-23], Botswana (n=1) [51], United Kingdom (n=1) [37], Kuwait (n=1) [25], Ireland (n=1) [44], India (n=1) [56] and Singapore (n=1) [50]. As indicated in Table 2, the majority of studies use a survey as a part of their methodology (n=24) [12], [18], [20], [25], [26], [30], [31], [38]–[43], [46]–[50], [52], [54], [56], [57], [63], [66] with citation analysis following (n=8) [33], [36]–[39], [59], [61], [62], [65] (Table 2). The most frequently cited frameworks were ACRL ILF and/or SET (n=7) [20], [35], [39], [45], [58], [63], [64]; ABET (n=5) [40], [51], [54], [55], [61], and Kulthau's ISP (n=3) [34], [61], [62].

The median sample size was 64 students. Several studies included students across different engineering disciplines, with breakdowns as follows: mechanical engineering undergraduates were the most frequently studied group (n=13) [12], [18], [30], [38], [41], [44], [45], [51], [53], [54], [57], [63], [66]; followed by first-year undergraduate engineers (n=10) [26]–[29], [32], [33], [36], [42], [47], [52], [59]–[62], [65]; civil (n=9) [12], [18], [37], [41], [49], [51], [57], [66]; electrical (n=6) [18], [41], [44], [51], [57], [66], computer (n=5) [20], [41], [50], [51], [66]. Limited demographic information was reported on the subjects; 12 studies reported the gender of participants [27], [28], [30], [40], [42], [50]–[54], [56], [66] all of these studies were had primarily male participants (Table 3).

Through analysis, four focuses emerged: *Student information behavior mirrors that of professionals*; *Design thinking as a guiding force for information behavior; Design work requires the use of a specialized information sources; and Methodological and theoretical approaches*

Summary: Student information behavior mirrors that of professionals.

Engineering students value accessibility and availability of information. There is a clear emphasis identified on web resources, personal connections, and 'alternative' information sources over traditionally academic ones. Kwasitsu [67] discussed how practicing engineers value accessibility and availability over quality when seeking information. This aligns with the "least effort approach" described by Tenopir & King [68] and confirmed by Allard, Levine, & Tenopir [4] where individuals go to the first available source often a colleague, their personal collection, or to a search engine such as Google. Student engineers, like professionals, engage in satisficing and optimizing their search process, hoping to spend time as "efficiently" as possible in order to manage competing roles and responsibilities [7]. Similarly, student engineers favor the use of web resources, personal networks including other students or professors, and personal collections before searching in databases [44], [46], [50].

The level of education attained influences the way an engineer interacts with information. With students, this means individuals in their final year integrate more academic sources than in their first-year in written tasks [28], [65]. This trend continues with graduate students using more sources with fewer errors than undergraduate students [37]. This is reflected in the literature around practicing engineers, with those having more education using a greater number and wider variety of information sources when gathering information [65]. Atman et al. compared students with practicing engineers and found that practicing engineers spent more time at each stage and significantly more time scoping their problem and gathering information [29]. Engineering faculty perceive the development of information literacy skills largely as a natural product of conducting research assignments, despite the evidence that practicing engineers will need to successfully navigate these skills in their professional work. This is further complicated by a faculty perception that hard work results in better information seeking, not direct instruction, especially when that instruction focuses on library-specific resources that may not align with disciplinary realities [46].

Summary: Design thinking as a guiding force for information behavior

Capstone design projects are turning points for information literacy in the engineering curriculum as they incorporate information seeking at multiple points in the process and integrate a broad assortment of information resources used for a variety of purposes throughout the projects [26], [34], [35], [53], [61]. These design projects are a fundamental part of engineering education, a primary catalyst for increased information seeking for engineering students, and have been identified as turning points towards information literacy for students in their later years of engineering programs [63].

These experiences are especially relevant in relation to design projects, where in contrast to researched work in other disciplines, typically have outcomes that are some combination of artifact like an object, data set, software program, or visualization as opposed to a more traditional research paper or report [7]. Understanding the use of information in design projects is further complicated by the fact that students often complete their design projects in teams, and therefore exhibit collaborative information behaviors [18].

Summary: Design work requires the use of a specialized information sources

Practicing engineers ideally spend significant time during the design process gathering and using information to scope the problem and generate solutions [28]. Mirroring this finding, design-focused undergraduate projects require engineering students to assess a broad range of possible information sources, increasingly using non-traditional resources including primary research, non-academic, and technical as they progress through their degrees, and finally complete capstone projects. Online user feedback, patents, environmental information, economic and business information, theoretical modelling information, trade publications, existing solutions, historical information, internal reports, white papers, scientific information, and objects themselves are examples of these sources [20], [31], [35], [53], [61].

To effectively navigate understanding increasingly complex information, students must consult both informal and formal information sources and will likely incorporate information from well beyond the engineering discipline [20], [28], [35]. This type of information seeking can be at odds with traditional information literacy instruction [12], [41]. Assessing the quality of such a broad range of possible information sources, particularly those outside traditional engineering materials, is a major challenge of information literacy in the engineering context [34], [35].

Summary: Methodological and theoretical approaches

Research into this topic is presented most frequently as peer reviewed journal articles, followed by conference papers. Most publishing on the topic of undergraduate engineering information behavior focused directly on traditional information literacy instruction and used empirical approaches to evaluate the efficacy of a teaching intervention [25], [26], [30], [49], [52], [58]. Using a comparative study design, Van Epps & Sapp Nelson studied the effectiveness of one-shot information literacy instruction in contrast to an embedded model with a sample of engineering undergraduates [59]. For data collection, most of the studies relied on surveys or questionnaires, with small number using formative assessment, content analysis, and multi-method assessment tools.

Discussion

Information seeking is multifaceted and constantly adapting as the types of information available change. To this point much of the research around information seeking behavior has focused on information as a whole, while not significantly focusing on individual groups at the undergraduate level. Closely linked to information seeking is identifying how undergraduate students, specifically undergraduate engineering students perceive and identify themselves. Engineering students in their first-year are 1.5 times less likely to identify themselves as engineers as they are once after they are past their first-year [69]. This study identifies that a number of engineering education courses and projects have students working as a part of a team, which provide a unique context to information gathering and sharing behaviours and may also indicate a unique mindset towards how, why, and what information is shared.

As engineering students progress through courses, co-ops, and internships perceptions of identity shift towards an increasingly professional identity [70]. Correspondingly, undergraduate engineering students' information behaviors may significantly diverge from other undergraduate students whose education has a more traditional research focus. Further, the emphasis on the design process and the corresponding increased use of alternative sources such as UX testing, trade publications, white papers, technical documents, as well as patents and standards, demands new considerations for teaching information literacy skills. This is of particular importance as we did not identify a substantial body of research investigating how these experiences, as well as other professional-focused learning, influences information seeking behavior over time, and what methods can be used to analyze those patterns.

Taken collectively, these observations suggest engineering student information behavior should be considered in some situations as distinct from that of other undergraduate students. There is a strong evidence base about how self-efficacy and motivation in engineering students can be unique in some ways from other disciplines [71]–[75]. The results articulate that the engineering student approach to information seeking is often from a different context, with a wide array of particularized information needs. By identifying the difficulty students experience in assessing the quality of sources, the results make a strong case for the need to define and understand of information literacy and information behavior in engineering broadly, and in the design context more specifically.

While the papers that contained defined methodological approaches to data collection and analysis, the studies frequently lacked a specifically stated theoretical perspective or model of information behavior, but instead relied on professional information literacy standards such as the ACRL Information Literacy Framework, its predecessor the ACRL Information Literacy Competencies for Higher Education, or learning outcomes dictated by professional accrediting bodies.

During the review no studies were identified that comprehensively combined examining the different influencers of engineering student information needs, information seeking, and external influences on studies. We also did not identify how this may be influenced by identity (gender, race), demographics (age, socio-economic-status), or social support (mental health, first generation higher education). These may be important considerations, especially considering the social nature of engineering education and information collection and organization, even outside an educational context. Future research should examine this through a theoretical framework that integrates the growing democratization of information. These understandings will help define how educators and librarians should approach teaching and integrating information literacy into their curricula.

In this review, education was found to have an impact on undergraduate student information behavior in the engineering disciplines. Vakkari examines empirical studies about the relationships between information searching and learning and finds some empirical evidence for the searching as learning process but identifies a lack of conceptual framework as barrier to conducting research into student learning [76]. The research identifies that, while we know engineering students emphasize easy access to information and depend on peers to help identify relevant resources, there is still a gap in knowledge around how undergraduate engineering students are learning through the use of information, what sources they value, what exactly are they learning, and where the gaps are in their knowledge.

At the core of the gaps defined by this scoping review is the lack of a consistent theoretical underpinning for this area of inquiry. Expansion on the integration that

Vakkari [76] and Wertz et al. [61], [62] have made with Kuhlthau's Information Seeking Process [77], search-learning, and undergraduate student's information behavior provides one possible approach to testing an established information behavior theory. Sandstrom's resource map methodology and continuum of foraging strategies could also provide a useful framework to be developed for empirical research [78]. Additionally, Dervin's Sense Making model is a well-developed theory with a number of associated data collection and analysis techniques that may be successfully employed to understand engineering student information behavior [79].

Limitations

Overall this review has many strengths. We believe it to be the first review to examine only engineering student's information seeking behaviors. Future research can build to include practicing engineers, and other STEM disciplines. Institutional access to databases did limit our results, particularly the lack of access to the Compendex (Elsevier) database. Beyond access limitations, studies that were identified through searching, but that could not be obtained through interlibrary loan or by directly contacting the author, were typically published prior to the coverage dates of the databases searched, resulting in a small bias toward more recently published information.

One of the main challenges in a review of this nature is that the interventions studied are heterogeneous. The nature of the language used to demark student information behavior, and even to denote undergraduate students is not consistent. In additional searching conducted, further efforts were made to address these limitations, though expanding the terminology used for searching only identified a small number of additional publications for inclusion. Hand searching also has the potential to miss relevant studies, as it relies on the level of comprehensiveness present in the literature reviews of the included studies. Additionally, through hand searching the authors identified a potential blind spot in identifying information about undergraduate engineering students that is found within studies focused more broadly on undergraduate information literacy as a whole, or that study, but do not distinguish undergraduate engineering students as a distinct population.

Conclusions and Implications for Future Research

At present a significant enough body of literature about understanding engineering student information seeking behavior does not exist. There is also currently not an established methodology to allow educators to systematically study this issue. While it is clear engineering information needs do not always align with traditional information seeking instruction familiar to university faculty and librarians, the learning curve required to meet the fluid and amorphous expectations of design-oriented work can be steep. While educators and information specialists have built strong curricula to instruct engineering students around information in individual case settings, there is significant potential for collaborative research and practice in developing best practices, tools, and strong methods around both understanding information seeking behavior, and taking that knowledge to inform how to teach engineering students critical information skills. Other clear directions for future research includes the potential of examining established information behavior theories such as Kulthau's Information Seeking process, Dervin's

Sense Making theory, and information foraging theory to validate or test in a more grounded engineering context.

Understanding undergraduate engineer information behavior presents a variety of challenges to practicing academic librarians and the programs they serve with more experimentation and validation required to establish best practices for approaching and serving the needs of this particular population. Librarians, at a minimum, need to develop an understanding of design thinking and processes and develop facility and flexibility in the information seeking tools they recommend and use throughout engineering curricula. Librarian expertise in organization of information and traditional knowledge management approaches present diverse and unique opportunities for supporting engineering student's information needs throughout their undergraduate education.

As stakeholders in engineering student success, educators and librarians can focus on understanding identity, external socio-cultural influencers, and other information approaches, such as critical appraisal to better inform how interventions in information seeking can be developed to best support student success. This area of research would benefit from collaborative and interdisciplinary research done by educators, information specialists, policy makers, professionals, and students to better inform how information seeking can be developed. More research needs to be done to examine the connection between the design process, information literacy, and information seeking behavior especially in the undergraduate engineering context. By broadening the body of research being done, the research can be developed to be more inclusive and diverse, which will help increase recruitment and support of underrepresented groups, and overall will improve student success in engineering. Additional research should be conducted to validate or confirm previous findings, build on existing assessment protocols, develop new protocols and methodologies, and explore the application of new theoretical frameworks.

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