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Examining In-Person and Asynchronous Information-Seeking Behavior Instruction Among First-Year Engineering Students

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Abstract

This is a complete evidence-based practice paper. The current COVID-19 global pandemic has required educators to pioneer online instruction even as they deliver it. This shift has particularly impacted first-year programs, in which training engineering students to find reliable information is fundamental to their professional development and ABET and CEAB accreditation criteria. Typically, information seeking is taught in person so that instructors and librarians can directly observe and guide student behavior, a practice still evolving but well-established by research. However, the effects of online information-seeking training and the sudden transition on students' learning are very poorly understood. Even less is known about the use of asynchronous instructional methods. This paper significantly enhances existing knowledge by directly examining the efficacy of in-person and asynchronous online instructional modalities. For 60 students in a mandatory engineering-communication course, we deployed an enhanced online baseline-assessment exercise to understand students' existing information-seeking behavior. Librarians then deployed an asynchronous online lesson to teach engineering research practices, critical evaluation, and information literacy. We evaluated the extent to which the online lesson impacted student information-seeking behavior and compared it to existing data from the prior year's classroom version. Our results demonstrate that the asynchronous learning module significantly enhanced the students' critical evaluation of sources and student outcomes were comparable with results in the previous synchronous course. These results have dramatic implications for how we understand students' baseline information-seeking behaviors, pedagogical design to bring about meaningful changes in students' use of sources, and how course design can incorporate effective asynchronous online delivery in diverse models.

Introduction

As the COVID-19 pandemic spread globally and governments began instituting large-scale lockdowns, academic institutions were faced with a new challenge: how to continue to provide high quality educational services when students and faculty were unable to leave their homes. Educators were asked to move their teaching materials online in weeks or even days, often lacking prior experience with online learning or the one-on-one support of overburdened instructional design experts [1], [2]. Students have been asked to continue their education under the assumption that these methods are an adequate substitute for traditional in-person learning.

Adjacent to the move to online teaching, it was important to maintain the first-year engineering training in information-seeking behavior embedded in the course, where students learn research skills to find and use information from a variety of sources to investigate engineering problems and technical developments. These skills help them succeed in their academic education but also prepare them for engineering careers with differing access to technical information. This training also helps to satisfy American Board of Engineering and Technology (ABET) and Canadian

Engineering Accreditation Board (CEAB) accreditation criteria, which mandate engineering graduates to be able to perform tasks requiring sound information-seeking skills, such as finding and using reliable information, conducting their work ethically, and locating standards and codes [3], [4]. As such, engineering students need comprehensive and effectively designed information-seeking instruction.

Traditionally, information-seeking behavior instruction is formally delivered in person, followed by in-class activities that give students opportunities to practice their skills. In this setting, instructors, librarians, and teaching assistants can directly observe and guide student behavior, while students can ask questions and receive real-time feedback. These interactions have been shown to improve learning outcomes by facilitating student engagement [5]. With classes moved online, educators are left to determine how to make their online content as engaging and effective as their in-person content.

However, the effectiveness of information-seeking behavior instruction delivered online is poorly understood, particularly when the online transition has occurred quickly. Instructors training engineering students in information-seeking will find little guidance about how to adjust their pedagogical approaches for effective online learning. The small body of research conducted in this area often relies upon self-report data and tends to be dated [6]. Even less is known about the impact of asynchronous instructional methods on student learning. The limited number of studies on this topic tend to use pre- and post-test methodologies that do not directly observe student behavior following instruction, making it difficult to draw conclusions regarding the practical impact of these interventions on their information-seeking behavior [7].

To address this gap, we report outcomes of information-seeking pedagogy for 60 first-year engineering-communication students in online asynchronous delivery and contextualize these results with prior work examining in-person learning and to earlier in-class instruction in the previous year to observe the impact of rapid online transition on engineering students [8]. In place of a pre-test, we used a baseline-assessment exercise to measure students' existing information-seeking behaviors. Students followed an online asynchronous learning module designed by librarians to teach engineering research practices, information-literacy skills, and critical evaluation of information. Students undertook an iterative writing process and submitted final projects, recording their resource-selection process. These were evaluated to determine the impact of the asynchronous learning module on students' information-seeking behavior. Finally, the results of this pedagogical reflection were compared to similar data recorded the previous year following in-person instruction of the same material [8]. Our results demonstrate that the asynchronous learning module significantly enhanced the students' critical evaluation of sources. These results have dramatic implications for how we understand students' information-seeking behaviors, pedagogical design, and delivery models.

Review of the Relevant Literature

The field of engineering strongly emphasizes the ability to apply concepts directly to problems [9], [10], which is typically taught within design courses or lab settings, but is often supplemented by real-world experiences including internships, co-ops, hackathons, and pitch competitions [9]. At the core of these experiences is the ability to find, comprehend, and synthesize information that is relevant and practical for the purposes of the project. Traditional literature and pedagogy do not emphasize either an established way to support student information-seeking or a theoretical model specific to engineering to guide teaching in a classroom. While there is foundational knowledge about information literacy that has begun to be adapted for an engineering context, this body of knowledge is still nascent [8], [11], [12].

Undergraduate Engineering Students and Information-Seeking

Research studying the information-seeking behaviors of undergraduate engineering students found that while the information-seeking behaviors of undergraduates are, in many ways, similar to those of professional engineers, their information literacy is quite different [14], [15]. Both practicing engineers and engineering students are most likely to use convenient sources first, usually preferring to consult colleagues or peers, their own information collections, or easily accessible internet search engines like Google [14], [16], [17]. Where these populations differ is in their ability to be critical of the information they find to ensure that it is reliable. Engineering students, particularly those in their first and second years, tend to be more confident in their information-seeking skills, rarely taking the time to develop search strategies and consider alternatives [15], [18]. Our previous pedagogical reflection following in-person instruction found similar results, showing that first-year engineering students rarely considered the credibility of a source prior to receiving training in critical evaluation of information [8].

With well-timed and effective educational interventions, undergraduate engineering students can acquire the information-seeking skills that will serve them throughout their academic careers and into professional practice. However, the literature provides little guidance regarding which approaches to information-literacy instruction are most effective. Some studies suggest that library instruction is most effective when librarians partner with faculty members to make the information provided as pertinent to the students' area of study as possible [19], [20], [21]. Similarly, it has been suggested that embedded, co-curricular or "just-in-time" information-seeking instruction is superior to the traditional "one-shot" information session that typically takes place over an hour of class time, once per semester [20], [21], [22]. Embedded, co-curricular instruction allows students to practice the information-seeking behaviors they are learning in a timely manner, identifying and applying their skills in different contexts across different assignments [20]. In practice, however, it may be difficult to implement "just-in-time" instruction, as the logistics of multiple or timely instruction can be challenging, and it can also be challenging for faculty members to create space in courses for just-in-time delivery, let alone repeatedly throughout the semester [23]. It has been suggested that the flexibility of online, self-directed learning modules may be the best way to give instructors the flexibility they need to include information-seeking behavior instruction in their course syllabi [23], [24].

Perceptions of Online Learning

There is limited information available regarding the effectiveness of information-seeking behavior instruction that has been delivered in an online context. In one such investigation, Baer created web-based video tutorials to teach undergraduate engineering students about databases, plagiarism, and copyright [25]. Using 20-question pre- and post-test assessments, Baer found the average student score increased from 10.63 to 13.30 following online instruction, an average increase of 2.67 correct answers [25, p. 6]. Tomeo [26] found similar results using pre- and post-test assessments to evaluate the effectiveness of asynchronous online tutorials given to second-year engineering students. While these studies suggest that online information-literacy instruction can be effective, it remains difficult to make comparisons between the effectiveness of online instruction and in-person instruction due to a lack of sufficient, rigorous literature to determine what is significant in this area. Research by Xu, Dong, and Nawalaniec [7] went a step further to directly compare the pre- and post-test results of students who had received information literacy and ethics instruction either during an in-person seminar or through an asynchronous online tutorial. Post-test improvements were noted for both seminar and online tutorial groups, leading the authors to conclude that online information literacy instruction is at least as effective as face-to-face instruction [7].

To assess student behaviors, Kajiwara, Taber, and Mullen [27] analyzed the references provided by undergraduate engineering students in assignments submitted before and after receiving online asynchronous information-seeking training. After reviewing the online web module, students used a greater number and a wider variety of sources to complete their assignments [27]. While this study was able to show that information-seeking instruction delivered via an online module can impact the information-seeking behaviors of undergraduate engineering students, it does not allow us to make comparisons to the effectiveness of in-person instruction.

Although some studies are able to provide evidence that online instruction can be at least as effective as in-person instruction, many of these studies note that their findings are tentative and require further investigation [7], [28]. As a result, some authors continue to view online instruction with suspicion [5], [29]. The primary criticism of virtual instruction is that it lacks the level of instructor-student interaction that occurs in-person [5], [29]. As a result, these critics argue that online instruction should be provided synchronously, imitating in-person education as much as possible [5], [29]. Burns, Cunningham, and Foran-Mulcahy [24] disagree, however, arguing that carefully designed asynchronous education has the potential to be as effective as synchronous or in-person education. While synchronous instruction may be better equipped to facilitate in-person interactions, with adequate planning, design, and unique pedagogical approaches, asynchronous instruction can be highly effective as well [24], [30], [31].

Methods

Pedagogical reflection has been called “the most valuable qualitative method of learning assessment that libraries have at their disposal” [32, p. 271]. By taking the time to review and critically analyze the impact of pedagogical approaches, librarians working with course instructors align themselves with pragmatic philosophy, learning what works best in practice and basing future decisions on this evidence [33], [34]. Having already completed a reflective case study on our in-person pedagogy, the reflection outlined in this paper is two-fold. We begin by reflecting on the outcomes of our asynchronous approach to emergency online learning and then compare these findings to the data collected following in-person instruction of the same information-seeking behavior material. This allows us to reflect upon and contextualize the past year’s instruction with the current landscape in a structured and rigorous way.

This pedagogical reflection examines existing teaching methods and only those changes necessary for online instruction due to the pandemic. Because our students were based around the world, our institution directed instructors to deliver classes asynchronously. Articulate was selected as the platform for asynchronous instruction as it is the most robust available hosted tool that meets the accessibility requirements at our institution. Our previous work observed 279 students taught by six instructors in thirteen sections; to mitigate the effects of instructor variation, 60 students were observed in three sections of a first-year engineering-communication course taught by a single instructor who was one of the six from the previous year. Teaching methods were not modified in any way to facilitate the reflection. Students were not the subjects of experimentation and were not assigned to control groups. All results were examined after all grades were submitted, courses were completed and closed, and no petitions had been reported. No analysis could have impacted students' grades. The reflection comprised six stages:

Stage 1: Observing existing information-seeking behaviors:

Students in civil, environmental, geological, electrical, and computer engineering take a dedicated engineering-communication course in the first term of their first year. To understand the students' baseline practices, we deployed a "pre-research worksheet" to elicit their behaviors as assessment for learning before training them in information-seeking practices. The worksheet directs students to select an engineering topic of interest, record sources that they have chosen to initiate their research, and write a reflection about their selection methods and criteria.

The Fall 2020 worksheet's first prompt directed students, "Find some sources on your own that you could use to learn about your topic. Find at least 3 of these sources. Then, enter the requested information in the fields below. This will create a start-point for you to pursue more research as the course progresses." We modified this from our previous prompt in Fall 2019: "Do some initial research: use whatever sources that you would generally use to start exploring a topic. Find at least 3 of these sources." We modified the prompt to reduce the potential impact of students' perceptions of the instructor's expectations on this assessment for learning and avoid prompting students to select specific search methods or kinds of sources.

The first prompt to find three sources enabled us to ask, "What kinds of sources did the students select on their own?" We elected not to measure whether students selected paper vs. internet sources, since the pandemic made it difficult for students to access libraries. We sorted the students' sources into the categories mainstream media, professional/trade sources, books, video, government websites including statistics and project information, peer-reviewed publications, academic sources (such as theses, conferences, university publications), corporate websites, blogs, online encyclopedias, and other (not fitting other groups, rarely found in this study).

The worksheet's second prompt directed students, "Explain how you found these sources and why you chose them for your future project." In this year's iteration, we removed the preamble that "Engineers must communicate their processes to others as part of the design process." We also removed "and what you might do differently to find information at the next stage of this project" to reduce the potential to imply perceived instructors' expectations.

The second prompt enabled us to ask, “Did the students select the sources for their relevance only, or also for the sources’ reliability?” We evaluated the students’ reflections with the following 5 descriptors:

1. **Not present:** The student does not demonstrate that credibility played a role in the selection process. E.g. “They will help me in the next stage of the project.”
2. **Limited:** The student shows a general awareness of the need to filter sources, such as using a library database, but does not identify any criteria otherwise to establish credibility. E.g. “Relied on Google scholar, then sorted by relevance.”
3. **Adequate:** The student describes at least a general policy of seeking credible sources, not merely relevant sources. E.g. “I tried to choose academic journals or articles from reputable publishers.”
4. **Significant:** the student describes an active process of considering specifics about at least one RADAR element (Relevance, Authority, Date, Accuracy, Reason) [13]: E.g. “I tried to find websites run by organizations that I would recognize ... I also looked for info on the authors to see how qualified they are.”
5. **Extensive:** the student specifically names enough criteria that the student is already employing the majority (3 out of 5) of the RADAR criteria.

Stage 2: Library intervention to train students to evaluate sources for credibility

After students had submitted their pre-research worksheets, the communication course deployed a modified online version of the information-seeking lesson deployed the previous year. The classroom version had included a seventy-minute interactive lecture given within the first four weeks of the term before the students began their iterative course projects. In that session, librarians engaged students in a discussion about how to select trustworthy information, and then taught the RADAR framework to assess the relevance, authors, date, accuracy, and rationale of a given source. Instead of directing students to rely on certain ways of searching for information, such as library websites or certain types of information such as peer-reviewed articles, students were instructed to evaluate all kinds of information actively. This strategy facilitates students to find reliable information once traditional scholarly information is not as easily available in professional contexts. Students practice this application by evaluating two sources with the RADAR framework: one shorter article selected by the instructor and one source related to their project idea. Students generally report that applying RADAR takes more time and effort than relying on a library website to filter information [8].

To accommodate online delivery, librarians developed an online module that segmented the lesson into four major sections and twelve subunits to allow students to tackle small units of learning. The module was built in Articulate cloud-based e-learning software and incorporated into our learning-management system. The module mirrored the content of in-person instruction, examining both library and alternative sources of information, ultimately encouraging students to consider a wide range of search options for more reliable information. The online lesson then taught the same RADAR process of critical evaluation with an instructor-selected short article. Students completed the practice worksheet and submitted it for the instructor to observe learning and provide formative assessment. The instructor then replicated this practice with a second iteration in which students found and evaluated a source about their project topics.

Stage 3: Students create final projects that must use relevant and credible sources

After an iterative writing process including a pitch memo and a progress report, students produced a final project proposal that demonstrated student outcomes of problem-solving, engineering design, and communications with various audiences. In the classroom version of this course, students were only required to cite their sources and provide a references section. In the online version, we improved upon assessment of students' use of sources by requiring students to label the type of source; rate the credibility of the source as no significant credibility, low, moderate, or high credibility; and then write 1-2 sentences to explain their choices.

Stage 4: Evaluation of final projects to assess student improvements in using credible sources

Students' final projects were assessed to determine the extent to which students were using reliable sources and how actively students assessed the sources' credibility and value. In our previous work, we rated students' selection of sources holistically with a 5-point Likert scale. However, we changed this approach for this iteration to gather more information. First, three readers independently assessed every single source used by applying a 5-point Likert scale:

1. **Not arguably a reliable source**, such as an unsubstantiated blog, corporate website with significant bias, or other source without some basic credibility.
2. **Limited credibility**: Significant limitations, such as a lack of many sources, but at least some reason to trust aspects of the source.
3. **Moderately credible**: Credible with some limitations. At least one element of RADAR is demonstrable, but not the majority.
4. **Largely credible**: With minor limitations, for example: well-researched with citations and written by a reliable author, but not peer-reviewed or scholarly.
5. **A clearly credible source**, such as a peer-reviewed article, scholarly book, or credible government website. Others may fit this description.

Second, we recorded the types of all sources used in the final report, with the same categories applied to the pre-research worksheet, allowing us to reflect on any patterns. Third, three readers independently analyzed the students' reflections about their use of each individual source, which we were not able to do in the previous work. Means were compared among readers, but future work will further explore how to assess inter-rater variation. This allowed us to observe students' active critical evaluation through their explicit comments. Here, we applied the same descriptors used to assess students' information seeking in the pre-research worksheet.

Stage 5: Comparison of students' critical evaluation at the beginning and end of the course

Our improved teaching methods allowed us to compare critical-evaluation outcomes at the beginning and end of the course, particularly directing the students to comment on each source's credibility in the final project. First, the students' explicit comments about the credibility of their sources were compared between the pre-research worksheet and the final project. Second, the types of sources that students selected were compared to observe any patterns or changes.

Stage 6: Comparison of synchronous classroom and asynchronous online courses for evaluation of credibility, quality of sources, and types of sources

To observe any variations between the classroom and online versions of this course and students' critical-evaluation outcomes, the students' reflective comments about their initial selection methods were compared. Also, the students' source selection for their final projects was compared across years and limitations were recognized with earlier data.

Results

Our findings corroborate our previous research results by demonstrating that a majority of students did not report or consider the credibility of sources selected for their engineering projects prior to the intervention. After the intervention, we report a significant increase in students' critical evaluation of the credibility of the sources used in their final projects.

1. What kinds of sources did students select on their own before the intervention?

The first reflection question asked what types of sources students consulted to pursue their research topics when relying on their pre-existing information-seeking experience. The pre-research worksheet asked students to find at least three sources that they could use to learn about their chosen engineering research topic. Students reported 181 sources in total. We previously reported that students overwhelmingly relied on the internet to find their sources; this time, we acknowledged that all the sources reported can be found online and instead divided "websites" into sub-categories. We then calculated the percentage of sources out of the total number of sources used and observed the number of students who used at least one type of each source media. The numbers of each type of source selected are as follows:

Table 1. Types of sources selected and reported by students as initial research sources.

Media Type	Sources	Percentage	Students using at least one	Percentage of students
Mainstream Media	33	18.2%	22	36.7%
Professional/Trade Sources	24	13.3%	20	33.3%
Books	2	1.1%	2	3.3%
Video	1	0.6%	1	1.7%
Government Sources	15	8.3%	13	21.7%
Peer-Reviewed	26	14.4%	16	26.7%
Academic Sources	23	12.7%	18	30.0%
Corporate Websites	33	18.2%	24	40.0%
Blogs	11	6.1%	11	18.3%
Online Encyclopedias	10	5.5%	7	11.7%
Other	3	1.7%	3	5.0%

It was not surprising that books comprised 1.1% of the sources used and were cited by only two students. Likewise, only a single student referenced a video. However, three main results were unexpected. First, we were surprised that 21.7% of the students relied on government sources without being instructed to do so. Second, a low proportion of students relied on online encyclopedias such as Wikipedia, despite having been given explicit permission to do so. Third, 26.7% of the students reported using peer-reviewed sources, and 30% reported using academic sources in the pre-research worksheet, even though they were in no way prompted to do so. The pre-research worksheet objective created a baseline standard of students' information-seeking behaviors, but this study cannot determine why they avoided certain source types. Instead, we asked questions about their rationale for choosing the sources they used.

2. How did students characterize their baseline information-seeking behavior?

Reflection question 2 asked how students described their information-seeking behavior when reflecting on their research from the pre-research worksheet to understand why students selected certain sources and how they found them. In the pre-research worksheet, students wrote up to two paragraphs in response to the writing prompt. Although 60 students submitted the assignment, only 57 wrote commentary about their source choices. We evaluated whether the students demonstrated evidence of critical evaluation of their chosen sources' credibility.

Table 2. Baseline ability of students to evaluate source credibility

Proficiency Designation	Number of Students	Percentage of Whole
Not Present	34	59.6%
Limited	6	10.5%
Adequate	6	10.5%
Significant	11	19.3%
Extensive	0	0.0%

59.6% of the students focused only on relevance and did not demonstrate any evaluation of the credibility of the sources they chose in their pre-research worksheet, and none of the students demonstrated an extensive proficiency in credibility evaluation. Students tended not to consider the RADAR elements of rationale, authority, date, and accuracy; rather, students often explained their research process as "simply googling my topic" and choosing relevant sources. 45.6% of students mentioned using Google, while 12.3% specifically reported using Google Scholar.

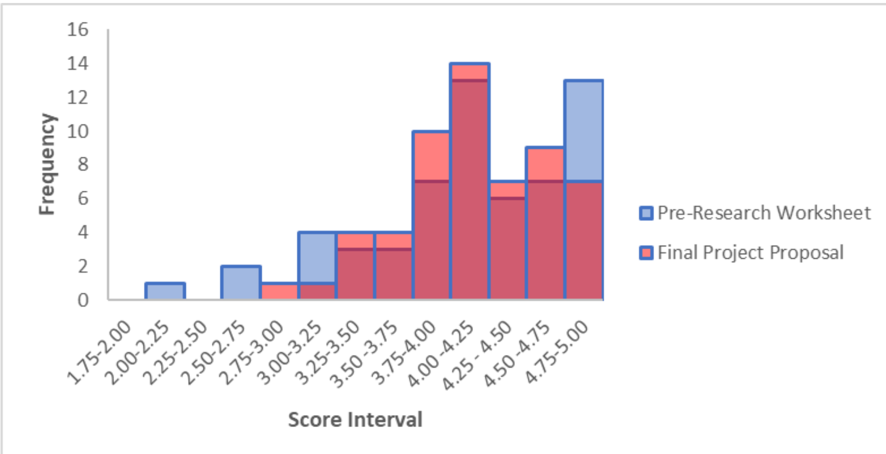
3. How much did students employ reliable sources in their final projects?

We assessed whether the students used credible sources more after learning the RADAR framework. 58 of 60 students completed the final project proposal, whereas 60 students completed the pre-research worksheet (P.Re). We calculated mean scores and standard deviations to aid our observations. In our previous work, the students' evaluation of source credibility on the pre-research worksheet was compared to the quality of the sources they selected on the final project proposal (F.Pr). We now directly compared these two (Tasks):

Table 3: Comparison for quality of source selection in pre-research and final projects

	Number of Students		Percentage of Students	
Proficiency Designation	Pre-Research Worksheet	Final Project Proposal	Pre-Research Worksheet	Final Project Proposal
Not Present	0	0	0.0%	0.0%
Limited	1	0	1.7%	0.0%
Adequate	10	6	16.7%	10.3%
Significant	29	35	48.3%	60.3%
Extensive	20	17	33.3%	29.3%

Although the number of students scoring as extensive dropped from 20 to 17, there was a conspicuous increase in the significant designation and decrease in limited and adequate outcomes in the final engineering proposal. When compared directly with the pre-research worksheet, the mean score (Mean) not only increased from 4.15 to 4.20, but the data also had a lower standard deviation (SD) from 0.66 to 0.47, which indicates that a more significant proportion of the students are closer to scoring around 4.20, suggesting an overall increase in their critical evaluation of research sources.



Task	Mean	SD
P.Re	4.15	0.66
F.Pr	4.20	0.47

Figure 1. Source quality on pre-research worksheet and final engineering project

For the pre-research worksheet, the number of students scoring well for the overall quality of their source selection was unexpectedly high. The score intervals with the highest frequencies were 4.00 – 4.25 and 4.75 – 5.00, indicating a majority of significantly reliable sources. In comparison, the final project proposal histogram shares the same peak as that of the pre-research worksheet but has a lower frequency in the highest score interval (4.75 – 5.00). However, the final project proposal score distribution is significantly tighter, ranging from 3.00 – 5.00 compared to a range of 2.25 – 5.00. The final project proposal also comprised more than double the number of sources used, which bolsters the trend's reliability when coupled with the decrease in standard deviation from 0.66 in the pre-research data to 0.47 in the final project proposals. Furthermore, there were no students who scored below adequate on the final project proposal; instead, there was a 12.0% increase in the percentage of students designated significant. To that end, we can infer the RADAR instruction correlates with a more consistent competency level throughout.

4. How did the students' evaluation of source credibility progress from the baseline to the final projects?

Students' responses on the final project proposal were assessed with the credibility criteria used for the pre-research worksheet to determine the extent of students' proficiency increase at the end of the course. 57 students wrote a commentary on the pre-research worksheet source selection, and 56 students did so for the final project proposals. Notably, no students were designated extensive on the pre-research worksheet compared to 33.9% on the final project proposal.

Table 4: Student ability to evaluate source credibility on pre-research and final projects

	Pre-Research		**Final Project**	
Proficiency	# Students	Percentage	# Students	Percentage
Not Present (1)	34	59.6%	0	0.0%
Limited (2)	6	10.5%	1	1.8%
Adequate (3)	6	10.5%	3	5.4%
Significant (4)	11	19.3%	33	58.9%
Extensive (5)	0	0.0%	19	33.9%
Total:	57	100%	56	100%
	Mean score: 1.89	Score SD: 1.21	Mean score: 4.24	Score SD: 0.51

The most striking result was the decrease in the percentage of students scoring as not present on the pre-research worksheet compared to the final project proposal from 59.6% to 0.0%. Furthermore, the number of students scoring as significant increased from 19.3% on the pre-research worksheet to 58.9% on the final project proposals, demonstrating a considerable improvement in the overall proficiency of the class. The mean Likert scores changed from 1.89 on the pre-research worksheet to 4.24 on the final project proposal as well. Intriguingly, the standard deviations associated with these mean values differ noticeably as well, with a standard deviation of 1.21 for the pre-research worksheet and 0.51 for the final project proposal, respectively. The larger standard deviation on the pre-research worksheet suggests that the students' reported consideration of credibility varied greatly. The much smaller deviation on the final project indicates that the students' competency level is comparably more consistent across the population, suggesting an improvement in the students' evaluation of credibility as a class.

5. How did the kinds of sources that students selected change after the intervention?

By examining whether students selected different sources after the librarian intervention and completion of scaffolded design projects from those on their baseline assessments, we considered whether they would select more explicitly credible sources (e.g. peer-reviewed or government sources) to a greater extent. The students used 398 sources on the final project. The results were then compared to those of the pre-research worksheet, as seen in Table 5 below:

Table 5: Comparison of types of sources used on pre-research and final projects

	Percentage of Sources Used			**Students Using at Least 1**		
Source Type	**Pre-Research**	**Final Project**	**% Change**	**Pre-Research**	**Final Project**	**% Change**
Mainstream Media	18.2%	16.1%	-2.1%	36.7%	56.9%	+20.2%
Profess./trade sources	13.3%	7.3%	-6.0%	33.3%	34.5%	+1.2%
Books	1.1%	2.3%	+1.2%	3.3%	8.6%	+5.3%
Videos	0.6%	0.3%	-0.3%	1.7%	1.7%	0.0%
Gov't documents	8.3%	13.6%	+5.3%	21.7%	36.2%	+14.5%
Peer-Reviewed	14.4%	21.6%	+7.2%	26.7%	62.1%	+35.4%
Academic Sources	12.7%	10.3%	-2.4%	30.0%	53.4%	+23.4%
Corporate Websites	18.2%	20.6%	+2.4%	40.0%	58.6%	+18.6%
Blogs	6.1%	6.5%	+0.4%	18.3%	29.3%	+11.0%
Encyclopedias	5.5%	1.3%	-4.2%	11.7%	8.6%	-3.1%
Other	1.7%	0.3%	-1.4%	5.0%	1.7%	-3.3%

One outcome showing dramatic change is that 62.1% of the students used peer-reviewed sources on the final project proposal, a 35.4% increase from the pre-research worksheet. Furthermore, peer-reviewed sources comprised 21.6% of those cited on the final project proposal, increasing from 14.4% on the pre-research worksheet. The percentage of students using academic sources and government documents also increased noticeably from the pre-research worksheet and the final project proposal. However, the results regarding the use of online encyclopedias were unexpected throughout the scaffolded course, because the course did not forbid their use and even encouraged students to consider and evaluate them. 11.7% of students used them on the pre-research worksheet, which decreased to 8.6% on the final project proposals. Moreover, encyclopedias made up a tiny portion of the sources used overall, beginning at 5.5% on the pre-research worksheet and ending at 1.3% on the final project proposals. This study cannot ascertain why students avoided the use of encyclopedias, which could be a subject of future research.

6. How did the students' critical evaluation vary between classroom and online instruction?

To observe variations in pre-research source selection between the two delivery modes, we reviewed the data collected for our previous work and performed a new analysis of the students' initial information-seeking practices in their pre-research worksheets.

Table 6: Comparison of students' ability to evaluate credibility in classroom and online:

	Synchronous classroom Fall 2019			**Asynchronous online Fall 2020**		
Descriptor	**Pre-research**	**Final project**	***p***	**Pre-research**	**Final Project**	***p***
1. Not present	97 (35.66%)	11 (3.94%)	<0.0001	34 (59.6%)	0 (0%)	<0.0001
2. Limited	74 (27.21%)	33 (11.83%)	0.0004	6 (10.5%)	1 (1.8%)	0.0437
3. Adequate	67 (24.64%)	82 (29.39%)	0.2116	6 (10.5%)	3 (5.4%)	0.2996
4. Significant	32 (11.76%)	82 (29.39%)	<0.0001	11 (19.3)	33 (58.9%)	0.0001
5. Extensive	2 (0.74%)	71 (25.45%)	<0.0001	0 (0%)	19 (33.9%)	<0.0001

Considerable differences emerge in the pre-research distributions of students in each category between the classroom and online versions. The results between years show variation that could be due to several factors. The refinement in task instructions in the most recent pre-research worksheet may have mitigated student perceptions of instructor expectations. The students may have received different training in information seeking than the students in our previous reflection. The difference in sample size may also influence the representativeness of the student sample in the current reflection.

We also compared the change in the students' active assessment of credibility in the pre-research worksheet and the final project in both the Fall 2019 classroom course and the Fall 2020 online course. Our previous work about the Fall 2019 classroom course made an indirect comparison between the students' reported practices on the pre-research worksheet and the instructors' assessments of the credibility of students' sources. We report that comparison here, despite its limitations. However, our design of the Fall 2020 online course required students to report their selection process of sources in both the pre-research worksheet and the final project. We also provide that more direct comparison here. We then improved on our previous work by evaluating the significance of each change with a two-tailed z test of two proportions with a confidence interval of 95% (α=0.05). P values lower than 0.05 reject the null hypothesis that the two proportions are the same, and therefore are significantly different.

Discussion

We set out to observe whether actively teaching critical evaluation of information could prompt students to enhance their assessment of the credibility of sources they use in the early stages of an engineering project. Results suggest that students generally assess sources for relevance as they enter university and choose or avoid sources without an explicit rationale for credibility. However, even when we encouraged students to find information where they preferred and did not restrict students to traditional search methods, the students developed significant attention to the credibility of sources and independently avoided sources of low credibility.

Several key results illustrate this effect. Students relied explicitly on Google to find information such as statistics at first, but substantially increased their use of government sources for statistics and project information, increasing from 21.7% initially to 36.2% in the final project. Only 11.7% of students selected online encyclopedias for their initial research, perhaps because they had been discouraged from doing so before starting their engineering program. Instead of forbidding them, the RADAR lesson recognized the value of online encyclopedias such as Wikipedia and asked students only to evaluate them for credibility, yet the use of online encyclopedias such as Wikipedia decreased to 8.6% on the final project. The instructor and librarians did not prompt students to use peer-reviewed articles, yet students drastically increased their use of peer-reviewed articles because they chose to do so: 26.7% of students selected at least one peer-reviewed article for their pre-research, but 62.1% did so for their final project.

These results exemplify assertions proposed in existing research. This course required students to examine the credibility of their sources across four major deliverables, indicating the impact of incorporating critical evaluation across different assignments [20] and making critical evaluation relevant to the students' engineering interests [19], [20]. Our results also exemplify the observation by Kajiwara, Taber, and Mullen [27] that teaching critical evaluation enables students to use a wide variety of non-traditional sources but evaluate them for reliability, giving them access to more types of useful and timely information.

As a population, students also transformed their explicit messaging about how much they evaluate sources for credibility. On the pre-research worksheet, 45.6% of the students used "Google" or derivative terms to describe their practice of finding information, though we never asked students to identify their chosen search engines. This result is in line with other observations that students resort to web searches, particularly Google, to find information [14], [16], [17]. 59.7% of students made no reference at all to credibility, while another 10.5% only relied on certain search engines to filter their searches, although a considerable minority of 29.8% did explicitly address credibility in some way. This exemplifies research observing that students do not generally consider information alternatives [15], [18] but focus on accessibility and relevance. However, on the final project, over 98% of students explicitly considered credibility for their source selections. Our revised teaching method of asking students to annotate every source briefly prompted the students to practice critical evaluation actively, and allowed us to observe whether they were still only assessing sources for relevance or were also assessing them for credibility. As such, students demonstrated information-seeking behavior more consistent with that of professional engineers, who access non-traditional information but carefully evaluate it for reliability. We cannot determine whether students have fully internalized this as a personal practice, but we can assert that iterating this practice across multiple deliverables prompted high engagement with critical evaluation of every source.

However, did the students' comments about evaluating credibility reflect the actual credibility of their sources? In our previous work, we only evaluated the reliability of students' sources holistically for each student, and did not evaluate the reliability of initial source selections at all. Our revised teaching method allowed us to analyze each source and observe the reliability of students' initial sources. The results reveal key insight that surprised us. We anticipated that students might have selected sources of questionable reliability in the pre-research worksheets. However, students selected generally reliable sources at the initial stage (score 4.15/5, significant); the reliability of their sources in the final project only rose to a mean score of 4.20/5. This outcome suggests some possibilities: we cannot assert whether the students anticipated the instructor's preferences and deliberately or even subconsciously tailored their selections, or whether they already possessed a subconscious inclination to assess sources for credibility. Further research and new methods must be devised to explore this further. Such results have implications for how we understand student information-seeking behavior and how educators can design pedagogy to cultivate an internalized practice of critical evaluation.

We also attempted to observe whether an asynchronous online course can train students in critical evaluation of information as effectively as a synchronous classroom course. While our online course lost the interaction afforded in the classroom, which some researchers have raised as a concern [5], [29], our results demonstrate that carefully structured online asynchronous teaching can cultivate significant and ongoing critical evaluation of information. By incorporating critical evaluation of information into a scaffolded engineering project with multiple deliverables in the online version, and by requiring students to explain their choices of sources, we were able to elicit a significant increase in the students' active evaluation of their sources. We were able to do so not by restricting where or how students access information, but instead by giving students agency to seek information where they choose and then training students to evaluate it with RADAR; students sought out reliable sources and avoided questionable sources of their own volition. These outcomes are consistent with the work of Xu, Dong, and Nawalaniec [7] and of Burns, Cunningham, and Foran-Mulcahy [24], who represent emerging views that carefully structured online teaching of information literary can be comparable to classroom versions.

This work presents limitations that should be explored in future work. First, we could not draw a true comparison between the Fall 2019 classroom and Fall 2020 online course because we improved the 2020 lesson. Future work could make a direct comparison with the new lesson structure. Second, incorporating critical evaluation into engineering courses presents some significant workload costs and challenges. Adding critical evaluation of information to deliverables increases workload and time requirements, potentially limiting the number of sources students would otherwise use. The iterative nature of critical evaluation in the course mitigates this effect by giving students opportunities to practice critical evaluation before the final project, but this work did not attempt to measure the increased workload effects for students or whether students avoided using more sources to manage their workload. Further research can explore the costs of adding iterative critical evaluation throughout a course for students, librarians, and instructors. Third, while we present some basic statistical analysis of the results, the work did not set out to focus on statistical analysis. As such, more sophisticated statistical tests such as the Wilcoxon test and larger sample sizes can be used to generate more insightful statistical results.

Conclusions and Future Work

This reflection presents compelling evidence that structured training in critical evaluation of information substantially changes students' active assessment of the credibility of sources even in online teaching. We directly observed that students at first generally focused on the relevance of sources conveniently available through search engines, although we newly observed that those sources were more credible than we anticipated. After intervention, we also observed that the students could perform critical evaluation of sources across multiple deliverables and continued to do so as we gave less-structured and more general instructions to account for their choices. In addition, we add initial evidence that the online version of this course can deliver results comparable to those from classroom courses, although this comparison was not the main objective.

These results have important implications for course design in first-year engineering programs to incorporate research skills directly into design documentation beyond generic library workshops. This involves tailoring library workshops to act as a step in an engineering design process when the students are engaged in pre-design. These results also demonstrate the value of teaching students to evaluate all information instead of circumscribing their search options, a skill that students will use when they enter industry and lose access to traditional academic resources. As such, replacing traditional information-literacy approaches with critical evaluation of information, possibly including the RADAR method, in engineering pedagogy better prepares students to use more types of information and know how to find information in professional contexts. Finally, our results suggest that modular online instruction that connects directly to students' design deliverables can stimulate observable changes in students' active critical evaluation of information. An online module is more flexible than traditional guest-lecture arrangements, more scalable, and more adaptable to the needs of individual courses. Results from synchronous and asynchronous courses show a significant change in the students' attention to credibility in their critical evaluation of information, essential to professional practice.

In the Fall 2020 online course, instructor bias could have played a role in generating scores. Future work can compare these results from year to year and in synchronous classroom instruction. Future research should find ways to observe the differences among students taught critical evaluation directly and those receiving traditional library visits or no intervention, and further explore the costs of implementing critical evaluation of information on student workload and the numbers of sources they choose. Finally, ethics approval would be needed to track students' use of critical evaluation across courses and years to better understand how much they internalize this practice. We conducted this approach in courses with class caps of 25, but whether this approach is scalable to larger class sizes also requires further study.

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