LEX LOCALIS-JOURNAL OF LOCAL SELF-GOVERNMENT
ISSN:1581-5374 E-ISSN:1855-363X
VOL. 23, NO. S5(2025)

SUSTAINABLE DEVELOPMENT RESEARCH IN THE CLASSROOM: AN EARLY START

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Abstract— Scientific literacy is often viewed as beneficial to a workforce dealing with an ever-changing world dominated by science and technology. The earlier learners encounter science, the argument goes, the better equipped they will be to solve the problems that such a world may present. Yet, scientific literacy, a key learning outcome of undergraduate education, is particularly challenging for non-STEM students with a didactic instructional background. Their past educational experiences have led them to adopt a passive approach to course materials, which may put them at a disadvantage with STEM students. In the present study, we asked whether introducing research practice early in the undergraduate general education curriculum could promote the attainment of learning outcomes covering scientific literacy in non-STEM students. A first-year communication course devoted to scientific literacy, offered by an English-medium university in the Middle East, was selected. The instructional method adopted to organize course activities was guided inquiry-based learning, which was intended to foster a sense of agency as well as a collaborative and supportive environment. At midterm, non-STEM students' scientific literacy was estimated to be below that of STEM students. Also, resistance to inquiry-based learning was more often expressed by non-STEM students. At the end of the semester, the scientific literacy of these two groups of students no longer differed. It was concluded that guided inquiry-based learning is an effective method for allowing non-STEM students to overcome past disadvantages in their exposure to science. Its ability to promote a sense of agency through problem-solving activities in a supportive environment may be primarily responsible for this outcome. Individual differences, however, existed, including non-STEM students' greater acquiescence to this instructional method's high cognitive demands than endorsement of its mode of learning.

Index Terms— general education, research practice, inquiry-based learning instruction, freshman students, scientific writing.

I. INTRODUCTION

Scientific literacy is commonly described as understanding and using scientific knowledge to identify questions and draw conclusions grounded in evidence [1]. It is assumed to benefit a workforce dealing with an ever-changing world dominated by science and technology [2]. Thus, scientific literacy may be considered a key component of general education undergraduate curricula. Frequently debated issues are the timing of academic courses devoted to scientific literacy, the depth of content coverage, and their effectiveness. For instance, early coverage of scientific literacy in courses of the general education curriculum is generally considered beneficial for a variety of reasons, such as repudiating popular misconceptions and illustrating the guidelines to evaluate evidence as trustworthy [3-4]. However, general education courses include students from diverse majors whose high school exposure to science may vary greatly. In Saudi Arabia, as in many other countries [5-9], students who are majoring in STEM disciplines (science, technology, engineering, and mathematics) have received considerable exposure to scientific knowledge and related applications during their last two years of high school. In contrast, students who are majoring in non-STEM disciplines (e.g., law and business) have not received the same exposure to such materials and practices. As a result, they may be at a disadvantage in a general education course devoted to scientific literacy open to all majors. Regretfully, limited data are available on non-STEM students' scientific literacy outcomes in the general education curriculum relative to those of STEM students. The reason is that often stripped-down scientific literacy courses are specifically created for non-STEM students [10-12].

The challenge faced by scientific literacy courses open to students of both academic majors is easily understood. If the course is not sufficiently 'basic' in its content to be viewed as 'doable', and engaging, non-STEM students' disadvantage may persist or even grow bigger. In contrast, if the course's content is viewed as 'doable' and engaging, it can become an opportunity for non-STEM students to gain scientific literacy and start major-level courses on an even field with STEM students.

What is a 'doable' scientific literacy course embedded at the start of the general education curriculum? A doable course is one that students may view as demanding but not above the cognitive resources that they can invest. It includes a curriculum that offers learners an understanding of the methodologies that guide the development of scientific knowledge. It is a course that highlights the fact that scientific understanding is often incomplete and transitory, so that students' confusion about contrasting scientific findings can be addressed. Without such an understanding, learners will find it difficult to trust science and its products. Of course, to foster engagement, it is a course that emphasizes the relevance of science in students' everyday lives and in the society they inhabit.

Cognitive load theory [13] defines a doable task as one that engages processes that do not overload the limited capacity of working memory. The theory identifies three distinct types of load: intrinsic, extraneous, and germane [14]. Intrinsic load emerges from the complexity of each of the activities that students are expected to carry out in a course. Germane load refers to how materials are presented to be learned. For instance, an instructional method that may generate a high germane load is inquiry-based learning [15]. It is an instructional technique that presents students with a problem that they need to solve on their own. In this setting, the instructor serves as a facilitator, guiding students to overcome obstacles without providing them with the needed solutions. Extraneous load refers to unnecessary, burdensome activities that do not contribute to learning. Thus, whereas either intrinsic or germane load refers to the mental effort that can lead to learning, the extraneous load is to be avoided at all costs.

To examine the impact of instruction under cognitive load on STEM and non-STEM learners, the present study selected a science literacy course taught through guided inquiry-based learning [16]. Brief lectures preceded class activities in which students were asked to complete independently a series of tasks, each presented as a problem-solving undertaking. The instructor served as a mere facilitator and, in some instances, as a collaborator rather than being the 'sage on the stage'.

Under these conditions, germane and intrinsic cognitive load were thought to be higher for non-STEM students due to their lesser familiarity with science materials and practices [17]. Namely, it was thought that non-STEM students may be at the start of the course at a disadvantage. However, if inquiry-based learning instruction is delivered in a format that makes activities engaging and 'doable', non-STEM students may catch up with STEM students. Alternatively, if the instruction fails to make activities engaging and 'doable', the disadvantage may persist or even grow bigger.

II. METHODS

A. Participants

Purposive sampling was used to recruit participants from a written communication course designed to develop and practice scientific writing. The course was mandatory in the first year of enrollment for both STEM and non-STEM students. Participants were 998 female freshmen whose ages ranged from 18 to 26. Their academic majors included STEM (computer science and engineering; n = 435) and non-STEM (business, law, and interior design; n = 563) fields. The participants were all Saudi Arabian nationals who had pursued their early education in the Kingdom.

B. Materials and Procedure

This field study was conducted over a period of 3 years, including 37 sections taught by 4 PhD-level educators. The selected course was taught in English, as most of the other courses of the general education curriculum and all courses of the students' selected majors. As engagement was considered critical for both STEM and non-STEM students [18], each semester, the United Nations' Sustainable Development Goals were used to identify the topic for a behavioral science study to be developed and performed by all freshmen enrolled in different sections of the course. For instance, the sustainable developmental goal of good health and well-being yielded a correlational study on anxiety, the goal of gender equality led to a sample study on gender role stereotypes, and the goal of responsible consumption and production yielded a retrospective case study on climate change. The instructional method adopted to organize research activities and writing was guided inquiry-based learning [19-20]. Generally, each class started with a brief lecture intended to illustrate the guidelines of a task presented as a problem-solving activity. Then, students were asked to complete the task at hand independently. They were encouraged to interact with peers and the instructor if they encountered obstacles. The instructor, who served in the role of facilitator of class activities, provided minimal feedback during class meetings to foster a sense of agency in the students and demonstrate the benefits of peer collaboration.

Course performance consisted of a research report on the study developed and conducted by the students, as well as a midterm exam and a final exam. The latter consisted of published abstracts or simplified abstracts to be used by students to perform information-processing activities. These activities included application, analysis, and evaluation, which the Bloom Taxonomy classifies as critical thinking operations [21]. The same information processing demands applied to the research report, which was organized into sections for scaffolding purposes: introduction, literature review, method and results, and discussion. Sections were written during the semester to culminate in a completed APA-style report. The report included all the sections mentioned above, as well as a title page, an abstract, and a reference section. A key aspect of this assignment was text revision.

At the end of the course, attendance and drop-out records were collected from the instructors. Furthermore, informal focus groups of 3-5 students (n = 87) were developed to understand students' responses to the course materials and instructions. Instructors were also asked to express their views on students' responses to inquiry-based learning applied to scientific materials. The study was approved by the Deanship of Research of the hosting university as following the ethical guidelines concerning the treatment of human subjects of the Office for Human Research Protections of the U.S. Department of Health and Human Services.

C. Data Analysis

All data were anonymized before analyses were conducted. Attendance scores served as an index of exposure to class activities, whereas the final exam and the research report served as summative assessment indices. For simplicity, the learning outcome of the final exam was defined as science-related methodological knowledge, whereas the learning outcome of the research report was defined as scientific writing skills (i.e., the use of a language for the concise expression of research endeavors). The midterm exam was used as a baseline to assess whether there were differences between STEM and non-STEM students in science-related methodological knowledge early in the course. The midterm exam was chosen because it provided a stringent assessment of potential scientific knowledge differences between STEM and non-STEM majors after having had sufficient exposure to inquiry-based learning instruction. All values were translated into percentages for easy comparison of outcomes.

Students' responses in focus groups and educators' independent responses were analyzed through thematic analysis. The coding reliability approach, which views coding as simply the 'process of identifying evidence for themes' [22; p. 3], guided the analysis. Inter-rater reliability for themes and categorization of comments under themes was ≥ 91%.

III. RESULTS

The descriptive statistics (mean, *M*, and standard deviation, *SD*) of performance variables are displayed in Table 1. Baseline knowledge was measured through the midterm exam. The final exam and the research report measured end-of-course knowledge and writing skills, respectively. Attendance records (attended class meetings / offered class meetings) served as a measure of course exposure.

Table 1. *Descriptive Statistics*

Variable	*STEM*		*Non-STEM*	
	M	*(SD)*	*M*	*(SD)*
Baseline Knowledge *	75.07%	19.95	72.10%	20.59
End-of-Course				
Knowledge	70.54%	19.63	68.92%	20.33
Writing skills	81.64%	20.35	82.26%	19.71
Course Exposure	88.29%	17.28	89.28%	14.81

Note: Significant differences are labeled with an asterisk.

One-way ANOVA was carried out with academic majors as the between-subjects factor. At baseline, the methodological knowledge scores of STEM students were overall higher than those of non-STEM students [$F(1, 996) = 5.26$, $MSE = 412.62$, $p = 0.022$, *partial* $\eta^2 = 0.005$]. At the end of the course, there were no significant differences between STEM and non-STEM students [$F \leq 1.61$, *ns*], including final exam grades (methodological knowledge measure), research report grades (writing skill measure), and attendance records (course exposure measure).

Course performance was also examined through pass and fail rates, leading to similar findings. Namely, there were no significant differences in the pass and fail rates of STEM and non-STEM students [□^{2} = 0.09, *ns*]. Out of 435 STEM students, 76% passed the course and 24% failed. Out of 563 STEM students, 77% passed the course and 23% failed. That is, it was a difficult course for both academic majors.

The drop-out rates (%) in the 37 sections of the selected course were analyzed through the Wilcoxon signed-rank test. We treated drop-out rates of STEM and non-STEM students as a within-subjects variable as they occurred within each of the 37 sections of the course. For STEM students, the median value was 7.69% (interquartile range = 6.87). For non-STEM students, the median value was 8.33% (interquartile range = 6.87). There was no significant difference between the two academic majors [$T = 10$, *ns*, with 4 ranks reporting increases, 0 reporting decreases, and 33 reflecting a tie].

Thematic analysis illustrated that individual differences existed in students' approaches to the instructional method. All comments that were reported by at least 50% of the students in focus groups were considered representative of students' views. Of particular interest were students' views of the inquiry-based learning instruction received in the course. At the end of the semester, all students reported that inquiry-based learning was more effortful than didactic instruction. However, non-STEM students tended to report acquiescence to the demands for cognitive effort and to the independence that the method asked of them. They were also likely to report concerns about the uncertainty that the method created about how to carry out course activities. Their preference for a detailed set of instructions led to worries about how independent problem-solving would impact their course grades. Instead, STEM students were likely to report endorsement of inquiry-based learning for its ability to foster a sense of independence and ultimately a sense of control and ownership over their work. Instructors noted that at the start of the semester, there was a palpable sense of uncertainty among students about the instructional method of the class. As the method was illustrated and practiced, resistance to it emerged mostly from non-STEM students. They were described by instructors as experiencing uncertainty about performance evaluations. Uncertainty avoidance reactions took the form of consistent requests for more detailed instructions in course activities that were viewed as placing unfamiliar problem-solving demands on students.

IV. DISCUSSION

The results of the present field study can be summarized in three points. First, STEM students started the course with an advantage in methodological knowledge. Non-STEM students' disadvantages in scientific literacy, including scientific reasoning measures, are often documented in the extant literature [23-24]. In our study, though, disadvantages were visible at midterm when students had received enough exposure to inquiry-based learning. At the end of the semester, this advantage disappeared. Second, STEM and non-STEM students did not differ in scientific writing skills at the end of the course. Their attendance and dropout rates were also equivalent. Thus, given the same overall exposure to course instruction and materials, initial differences in methodological knowledge disappeared. Third, although behavioral indicators of course engagement (attendance and dropout rates) were equivalent, non-STEM students were more likely to adopt an acquiescent attitude toward inquiry-based learning as the mode of instruction, whereas STEM students were more likely to endorse it. Thus, although inquiry-based learning was successful in equating the methodological knowledge of STEM and non-STEM students (as measured by application, analysis, and evaluation), it did not succeed in puncturing attitudes. These individual differences need to be addressed as they foretell the reemergence of a non-STEM disadvantage. Nuhfer et al. [7] warn that scientific literacy is unlikely to change substantially over a single course. Thus, other courses fostering scientific literacy within and outside the general education curriculum may be required before non-STEM students' scientific knowledge base is stabilized.

The findings of an earlier study [8], conducted on the same female population, illustrate a possible mechanism through which inquiry-based learning might have worked to equalize performance between STEM and non-STEM students. In this study, STEM students' self-confidence was higher, but their initial science literacy performance was surprisingly lower. Nevertheless, STEM students were more likely to complete the course successfully than non-STEM students, suggesting that STEM students' initial poor performance was a wake-up call to increase effort. In the present study, non-STEM students had a lower initial performance. These contradictory findings point to the instructional method in the earlier study, which included more didactical than inquiry-based learning activities. The latter might have fostered the initial higher performance of non-STEM students. In the context of inquiry-based learning, non-STEM students might be those who are confronted with less desirable initial performance. That is, the high cognitive demands of inquiry-based learning activities might place a heavier burden on non-STEM students, leading to uncertainty (extraneous cognitive load) and thus lower performance. Whether initial performance differences were related to differences in self-confidence remains unclear, as we did not measure confidence.

The present study has limitations that need to be addressed in future research. First, the exclusively female sample did not allow us to examine gender differences. Second, high-school performance data were not available to us, thereby making it difficult to assess the relationship between high-school preparation and university-level attainment. Third, students' self-confidence was not assessed. Also, learning outcomes involving the cognitive operations of application, analysis, and evaluation of scientific materials were not differentiated. Fine-grained distinctions in the cognitive processes demanded by course activities might have uncovered selective areas of intervention for the development of the scientific literacy of non-STEM students.

V. CONCLUSION

The present field study indicates that a course modeled for both STEM and non-STEM majors can be successful in equating basic scientific literacy competencies. In a society, such as that of Saudi Arabia, undergoing a profound restructuring of its economic engine, behavioral and attitude patterns toward scientific literacy are important indicators of needed interventions to increase the likelihood of students' future professional success. Inquiry-based learning instruction may compensate for undergraduate students' discrepancies in scientific literacy arising from past educational experiences. Yet, one semester may not be sufficient to puncture resistance to scientific endeavors, which is likely to arise from the greater cognitive load and uncertainties of autonomous problem-solving activities.

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