A Tool for Gaining Insight on Students' Self-Directed Learning Skills

Abstract

New engineering educators need to be equipped with instruments that can provide easy and meaningful insight into students' self-directed learning (SDL) status so they can better foster students' success. Students who are self-directed learners can independently initiate and take full responsibility for learning, effectively utilize available resources in the pursuit of their goals, develop awareness of their learning, and demonstrate the appropriate attitude essential for individual and collaborative learning. Despite these benefits, developing SDL skills in engineering students is often overlooked. To address this, educators have a facilitating role to play in the development of engineering students' SDL skills, however, this role can be challenging for them due to the (a) high cost of using SDL instruments, especially in a large classroom and (b) uncertainty about the validity of SDL instruments. Moreover, these challenges may be more pronounced for new engineering educators. This study addresses these challenges by reporting the validity evidence for an SDL assessment instrument called the Self-Rating Scale of Self-Directed Learning (SRSSDL). The SRSSDL instrument has been widely utilized in medical education, but in this study, it was modified for the engineering education context. The utility of this 8-constructs, 46-item scale was demonstrated in engineering education with 111 undergraduate students across all academic levels, and the validity test was conducted in line with the contemporary validity framework. The result of the validity test of the SRSSDL revealed inconsistencies or instability of its constructs in the engineering education context.

Keywords: Self-directed learning, Validity, Psychometric Analysis, Confirmatory Factor Analysis, Lifelong learning, Undergraduate, Instrument

I. Introduction

Self-Directed Learning (SDL) skills are important for students irrespective of their ages. By acquiring SDL skills, students can demonstrate a better handle or ownership of their learning process. Knowles described SDL as "a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing, and implementing appropriate learning strategies, and evaluating learning outcomes" [1, p. 18]. SDL skills are essential cognitive skills for workplace [2] and society [3] that can be consciously cultivated over time.

Self-Directed Learning entails autonomy and taking responsibility, many students may find these capabilities challenging to cultivate as instructors often bear significant responsibility for determining what students should learn [4]. Nevertheless, instructors play a pivotal role in facilitating students' engagement in SDL practices and progressively developing students' SDL skills [5], until they develop autonomy (i.e., manage all or most of their learning process on their own). To effectively carry out this role, it is important that new educators become familiar with and adopt relevant teaching approaches.

A significant aspect of fostering students' SDL involves assessing their SDL skills. In engineering education, quantitative assessment of students' SDL skills has been achieved through analysis of pre-and post-test scores [6]-[7]; assessment of the impact of an intervention on SDL skills [5]; and longitudinal analysis [8]. Likewise, through the use of course modules covering topics on self-directed learning [9]-[10]; problem-based curricula [11]-[12]; engineering projects [13]; journaling [14]; and reflective writing [15], instructors have monitored and assessed changes in students' SDL skills. These approaches were described in studies such as Fellows et al. [3] that entailed a range of classroom and project activities designed according to the Hersey and Blanchard's Situational Leadership Model [16]. During the activities, students' SDL ability was assessed in Four stages - Dependent (stage 1), Involved, Interested, and Self-Directed (stage 4). Ulseth [17] explored the experiences of students taught using Problem-Based Learning (PBL) to gain in-depth understanding of the potential influence of a PBL curriculum on students' self-directed learning. Lombardo et al. [18] described a self-directed pedagogy adopted during Harvard-HKUST Summer Design Experience, where engineering students went through several iterations of the "design-build-test-refine-present" process. During the program, students demonstrated autonomy in investigating problems, learning from field experts, and devising potential solution paths. Similar studies have been conducted to foster SDL skills in engineering education in [19]-[20].

These studies have not only highlighted qualitative and quantitative methods for assessing engineering students' SDL skills, but they have also revealed a potential gap in the quantitative assessment using instruments suitable for engineering education. This study addressed this gap by adapting an SDL assessment instrument used in nursing education in Italy for the engineering education context in the United States. The purpose of this study was to examine the validity of the Italian SRSSDL instrument [21] using SDL data from undergraduate engineering students in United States and to illustrate its validity evidence. This research fills a crucial gap in the literature on the quantitative assessment of engineering students' SDL skills and provides new and more established engineering educators with an SDL assessment tool to help them gain actionable insights into their students' SDL capabilities. These insights can aid in designing interventions and developing effective learning strategies that would improve engineering curricula and enhance engineering students' SDL skills.

II. Literature Review

A. Andragogy and Self-directed Learning

A widespread belief in the 19th to 20th century was that in timed assessments, older adults were often outperformed by younger counterparts, suggesting that younger adults were better learners [22]. Some researchers believed that the aging process influences various cognitive functions such as recalling, information processing, problem-solving, as well as the speed of doing these things [23]. Consequently, there was a pursuit to distinguish between adult learning and child learning. Contributing to this distinction was Knowles [24] description of andragogy as the science of facilitating adult learning and pedagogy as the science of aiding children in their learning process. Self-directed learning became a model that distinguished adult learners by their ability to plan, carry out, and evaluate their learning at their own time, despite juggling job and school responsibilities [23]. However, with the view that learners become increasingly self-directed as they mature, there was a growing argument that self-direction should be developed in younger learners too [23].

In recent times, the distinction between children and adults has become less distinct; some scholars argue that andragogy falls within pedagogy [25] and others have explored andragogical methods with participants aged 18 and above [26-27]. Studies have also highlighted the benefits of SDL across all ages, revealing that SDL is positively related to formal educational experiences [28] and life satisfaction [29]. Studies have also emphasized the importance of SDL for academic learning and lifelong learning [6].

In essence, andragogical approaches to instruction (e.g., problem-based curricula [11], reflective writing [15]) provide opportunities to engage in various aspects of SDL. These approaches develop skills necessary for SDL (e.g., goal setting and reflective practice [30]-[31]) and promote autonomy and responsibility-taking (e.g., PBL [18]). When implementing these strategies, assessment tools to detect the impact on students' SDL abilities is desirable.

B. Self-Directed Learning Skills Assessment

Various SDL scales or instruments have been utilized in both education and industry to assess SDL skills. A notable example is Guglielmino's Self-directed Learning Readiness Scale (SDLRS) which Guglielmino et al. [32] anticipated would be of a big implication for business, industry, and higher education. The SDLRS has 58 items across eight constructs - openness to learning opportunities, self-concept as an effective learner, initiative and independence in learning, informed acceptance of responsibility for one's own learning, love of learning, creativity, future orientation, and the ability to use basic study and problem-solving skills [32, 33]. In the industry context, correlation and regression analysis of data gathered using Guglielmino's SDLRS revealed that SDL explained the productivity of 267 lawyers in Lithuania [34]. The same scale was used in a study by Durr et al. [33] to examine the readiness for self-directed learning of 607 employees at a manufacturing firm. Analysis based on the occupational categories of the employees revealed statistically significant differences among mean SDLRS scores, with the highest mean score in the sales occupation category.

In the education context, Guglielmino's SDLRS was used by Jennings-Arey [35] to gain insight into 20 students’ perception of their self-direction in an introductory American Sign Language (ASL) class. Findings from this study revealed that students in majors that required them to learn ASL had self-acquired SDL skills. Likewise, among 272 nursing undergraduates in Thailand, Guglielmino's SDLRS revealed high level of readiness for self-directed learning [36]. Furthermore, a significant correlation between engineering students’ SDLRS score, and their grade point average was found in the study by Litzinger et al. [8]. The wide utilization of Guglielmino's SDLRS confirms its resourcefulness in assessing self-directed learning in industry and higher education [32].

However, Guglielmino's SDLRS was not without limitations. Critics of the scale raised issues with the wording and homogeneity of its constructs [37]-[38]. Its reliability was also questioned when a poor correlation between faculty assessment of students’ SDL skills and students’ assessment of their SDL skills was observed in a study by Long and Agyekum [39]. Faculty tended to give lower SDL ratings to Black students and higher ratings to older students. Other SDL instruments developed after the Guglielmino's scale contained constructs described differently to better suit the new settings. For example, in a study by Fisher and King [40] involving 201 undergraduate nursing students in Australia, a Self-Directed Learning Readiness (SDLR) scale was developed with 42 items categorized into three constructs - self-management, desire for learning, and self-control. Upon examination of these constructs, variances, and redundancies were observed, leading to a revision that resulted in a new scale with 29 items [41]. Still, critics suggested that the revised SDLR scale was not parsimonious (i.e., not concise) [42], they recommended another scale that consisted of 36 items in four constructs - critical self-evaluation, learning self-efficacy, self-determination, and effective organization for learning [43]. The critics asserted that the recommended scale was more concise and highlighted theoretical dimensions required for assessing SDL skills in medical students. The inconsistencies of Guglielmino's and other scales, as well as the cost implication of using some of them, served as discouraging factors for their adoption in the current study.

As illustrated, validity studies on SDL scales have often led to the creation of new scales considered more consistent than the previous one. Other examples of SDL scales that emerged from the validity studies of prior scales are the Self-Directed Learning Instrument (SDLI) [44] and the Self-Rating Scale of Self-Directed Learning (SRSSDL) [45]. The SRSSDL was originally a 60-item self-directed learning assessment instrument developed by Williamson [46] through a Delphi technique. This instrument was organized into five constructs - awareness, learning strategies, learning activities, evaluation, and interpersonal skills.

To investigate the validity of the SRSSDL, it was administered to undergraduate nursing students in the United Kingdom. The measure of internal consistency of this instrument suggested sufficient correlation between its items and all five constructs. Cadorin et al. [45] corroborated this result in their investigation of the construct validity of Williamson's SRSSDL with 334 working nurses in Italy, suggesting that the instrument was valid and reliable in the Italian context. However, upon subsequent validity study by Cadorin et al. [21], involving 847 participants in nursing and radiology, a modified SRSSDL instrument was developed. This SRSSDL consisted of 40 items and eight constructs - awareness, attitudes, motivation, learning strategies, learning methods, learning activities, interpersonal skills, and constructing knowledge. Following this study, yet another version of the SRSSDL instrument with 13 items and four constructs (i.e., awareness, attitudes, availability, and motivation) was developed by Cadorin et al. [47].

A concurrent validity study [48] involving the Italian SRSSDL [21] and the Taiwanese SDLI [44] revealed a 66.4% common variance, suggesting that the constructs of both instruments substantially correlate or tend to overlap. Though this result raised confidence in the validity of the Italian SRSSDL [21], that confidence was reduced in the results of the study by Behar-Horenstein et al. [49] which involved 207 undergraduate pharmacy students in the United States. Their investigation of the validity of Williamson's and Cadorin's SRSSD resulted in a new SDL instrument with 55 items and five constructs - intrinsic motivation, awareness, collaboration, reflection, and application. The authors concluded that regarding Williamson's and Cadorin's SRSSDL, "there is a concern about stability" [49, p. 287].

C. Contemporary Validity framework

The importance of validity in research has been emphasized over the years with the emergence of various validity models. In Brennan [50], Michael Kane defined validity as the "development of evidence to support the proposed interpretations and uses of a measurement" [p. 17]. Kane [51] conducted a review where he discussed the initial validity models that comprised construct validity [52], content validity [53], and criterion validity [54]. These three models form the classical validity framework [55]. While these models had their advantages, they also had limitations, prominent ones being their lack of consideration for the value implications of score meaning and the social consequences of score use. With these limitations, arguments, inferences, and interpretations of validity necessitated the development of the contemporary validity framework, which provided a more nuanced, unified, and practical view of validity [56]. According to Downing [57], contemporary validity represents construct validity which requires multiple sources of evidence or contains multiple facets such as content, response process, internal structure, relationship to other variables, and consequences (Table 1). Other views about contemporary validity framework were framed within these facets [55], [58]-[59]. For research purposes, the Standards for Educational and Psychological Testing provides a comprehensive guide and emphasizes the evolution and adaptation of validity frameworks to address complexities of contemporary educational contexts [59].

Table 1. Contemporary validity framework as applied in this study (adapted from [55])

Source of Evidence	**Definition**	**Evidence Collected**
Internal structure	Relationship among the instrument's items and how they relate to the construct they measure	Internal consistency Confirmatory factor analysis
Content	The degree to which items of an assessment instrument are relevant to and representative of the construct they intend to measure [61]	Expert review of the SRSSDL items
Response process	"Fit between the construct being measured and nature of the responses of the individuals completing the instrument or the individuals conducting an observation using the instrument." [62, p. 162]	Exclusion of similar responses and quality check questions
Relationships with other variables	The degree to which measures in similar or dissimilar tests outside of the current study are positively or negatively related [62]	Correlation between the SDL scores in this study and those in [63]
Consequences	The impact, beneficial or harmful (intended or unintended) of assessment [64]	Test preparation and administration procedure

The studies discussed above have highlighted the need for a more consistent SDL assessment in engineering education. Of the SDL assessment scales discussed, Cadorin et al.'s [21] SRSSDL was considered suitable for the validity current study for two reasons. First, its items aligned with the skills to be examined in engineering students as part of a larger study that explores the impact of metacognitive learning strategies on their self-directed learning. Second, it had been widely used in nursing education and its validity has been confirmed in related disciplines [48, 60]. Examining the SRSSDL's validity in a different setting- engineering education, was necessary to ascertain its suitability for the SDL assessment of engineering students.

III. Methods

A. Instrument Design

Cadorin et al.'s [21] SRSSDL instrument which contained 40 items and 8 constructs (Appendix A) was used in this study. Prior to its use, modifications were done by rewording some items, splitting some items that were compound statements, and adding new items. For example, item 7 was divided into two separate items- 7 and 8, while item 23 was divided into items 23 and 24. Minor rewording of items 13, 21, 31, 36-39, and 45-46 was done to improve their clarity, and four new items (i.e., 32-34 and 39) were added to the instrument to round out strategies that engineering students often use for learning. These modifications resulted in 46 SDL items which were necessary to eliminate ambiguity and to enhance comprehension for the participants. This final 46-item SRSSDL instrument (Appendix A) contained the same eight constructs as in [21]. Separate from these 46 items were four quality check items worded as "For quality assurance purposes, please select "Never" for this statement", the remaining three items were worded in the same format but asked that "Seldom", "Often", or "Always" be selected. Item 17 under the motivation construct was the only negatively constructed item.

Drawing from the literature on the SRSSDL instrument, "awareness," "attitude," and "motivation" constructs were described as "the main antecedents of the presence of an effective SDL skill" [21, p. 1515]. These constructs entail taking responsibility for and understanding the SDL process. They also entail self-evaluating attitudes and feelings used to drive learning. The "learning strategies," "learning methods," "learning activities," and "interpersonal skills" construct entail skills needed to effectively manage the SDL process. They involve utilizing diverse strategies and methods, such as informal discussions, individual study, managing self-instruction modules, guided study, and teamwork. The eight construct- "constructing knowledge" considers learners' ability to direct their own "cognitive behavior and to construct knowledge in an active and autonomous fashion, through a structured process that is based on experience and not on the knowledge transmitted" [21, p. 1515].

B. Participants and Settings

This study was conducted at a midwestern research intensive (R1) university in the United States. The participants were undergraduate engineering students across all academic levels, enrolled in four engineering courses offered in the Spring 2023. The first-year level course entailed the use of Microsoft Excel for problem solving techniques and procedures, plotting graphics, and doing computations with MATLAB. The course for senior level students entailed analysis, design, and investigation of engineered steel structures, while the junior and senior level course involved application of principles of environmental engineering in the design of water, air, and waste management systems. The fourth course was a junior and senior level introductory course to transport of energy and mass in biological and environmental processes. The instructors for these courses were recruited for this study by the primary researcher and recruitment of participants was based on the instructor's interest in using structured reflection to facilitate self-directed learning skills in their classes.

The SRSSDL instrument was administered to the participants at the start (pre- assessment) and end (post- assessment) of the semester. The SDL assessment was not connected to a specific course module, homework, or project. It applied to the entire course, and it was expected that students' perception of their experience in a course's activities would influence their responses to the items of the SRSSDL. Only post-assessment data was used in this study because it was expected to contain more reliable data about students' perception of their SDL abilities. Nevertheless, the pre- and post-assessment data were used to provide instructors with descriptive statistics and interpretations of trends in students' SDL skills. This report enabled instructors to learn about their students' use of SDL strategies in the respective courses.

111 students out of the 159 students that enrolled in all four courses were eligible for this study (i.e., n = 111, N = 159). The demographics of the participants included 55 males, 53 females, 3 other students (e.g., either non-conforming or preferring to not to disclose their gender) (Table 2). The majority of the female students were first-year students (24), while the majority of the male students were juniors (16). In line with the requirements for human subject research, the approval of the university's Institutional Review Board (IRB) was obtained for this study.

Table 2: Demography information of the participants of this study

Academic Level	Female	Male	Other	Total
First year (Freshmen)	24	10	-	**34**
Second year (Sophomore)	3	9	-	**12**
Third year (Junior)	18	16	3	**37**
Fourth year (Senior)	7	15	-	**22**
Fifth year (Super senior)	1	5	-	**6**
Total	**53**	**55**	**3**	**111**

C. Data Collection

The SRSSDL instrument was administered to the participants via $qualtrics^{XM}$ (an online survey platform) two times during Spring 2023 as part of the course they were enrolled in. The first round of data collection (pre-survey) was conducted within the first or second week of the semester, while the second (post-survey) was administered during the two weeks leading up to the semester's end. On a 5-point Likert scale of "1 = Always", "2 = Often", "3 = Sometime", "4 = Seldom", and "5 = Never", students rated the frequency with which they demonstrated the SDL behavior or action described by each of the 46 SRSSDL items. For the negatively structured item, a reversed rating applied. Although there was no specific time allotted to complete the survey, the average completion time was about five minutes. The participants' ratings of their SDL skills were downloaded as .csv Microsoft Excel file.

Prior to data analysis, cleanup of the raw data was conducted in .xlsx Excel file format. Based on four exclusion criteria that entailed not consenting to participation, failure to complete the survey, failure to select the correct quality check options, and providing the same response to 40 or more items of the SRSSDL, some data entries were removed. The resulting 111 SDL data entries from the post-assessment were used for this study. The .xlsx Microsoft Excel document of these SDL data was reconverted to .csv file format suitable for R-studio software computation during data analysis.

D. Data Analysis & Results

As per the contemporary validity framework in Table 1, inferential statistics (i.e., confirmatory factor analysis, Cronbach's alpha computation) were used to show internal structure validity. Descriptive statistics (i.e., mean, and standard deviation) were used to illustrate relationship with other variables, while the procedures of the study provided evidence of content validity, response process, and consequences.

1. Internal Structure Validity

To show evidence of the internal structure validity of the SRSSDL instrument, confirmatory factor analysis (CFA) and internal consistency reliability were conducted.

a) Confirmatory factor analysis

Confirmatory factor analysis was used to investigate the measurement invariance of the 8-factor model proposed by Cadorin et al. [21], [60]. CFA was performed using the lavaan package of R-studio version 2023.09.1+494. The SDL data were read into the R software as a .csv file with 46 columns (items) of the SRSSDL modeled as a composite of 8 factors (latent variables). The resulting model fitness to the SDL data was then inspected and interpreted. For the cut-off criteria, recommendations by Everit and Hothorn [65] and Hu and Bentler [66] were followed. The indices for acceptable fit of the model were: comparative fit index (CFI) ≥ 0.95, Tucker–Lewis's index (TLI) ≥ 0.95, root-mean-square error of approximation (RMSEA) ≤ 0.06, and standardized root-mean square residual (SRMR) ≤ 0.08.

The results of the Confirmatory Factor Analysis, as shown in Table 3, revealed that both the CFI and TLI were below 0.95. The RMSEA exceeded 0.06 and the SRMR exceeded 0.08. These indices collectively implied that the proposed 8-factor model provided a poor fit to the SDL data. That is, the statistical model did not adequately represent the underlying relationships between the variables in the SDL data, thus highlighting the need for improvements to the model.

Table 3. CFA results showing goodness of fit indices of the 8-factor SRSSDL model

Goodness of fit indices	**46 items**
Test statistic (χ^2)	1636.530
Comparative Fit Index (CFI)	0.635
$\mathrm{P-value}$ (ρ)	0.000
Tucker-Lewis Index (TLI)	0.607
Akaike (AIC)	11403.160
Bayesian (BIC)	11852.940
Sample-size adjusted Bayesian (SABIC)	11328.350
RMSEA (90% CI)	0.08 (0.073–0.086)
SRMR	0.091

b) Internal consistency

Internal consistency was examined using Cronbach's alpha (α) in the psych package of R-studio. Cronbach's α was used as the measure of the SRSSDL's reliability. Typically, to illustrate reliability, all items should correlate with the total reliability score from the scale [67]. As recommended by Cronbach et al. [52], a value ≥ 0.70 was considered acceptable for scale reliability. Cronbach's α was computed for the 46-item and 8-factor instrument (version 1) and the reliability output revealed that three factors- "Learning Methods", "Motivation," and "Learning Activities" fell below 0.70, thus failing to meet the acceptable criteria (Table 4). The output also suggested that dropping items 15 and 17 could enhance the reliability of the "Attitude" and "Motivation" constructs. Additionally, the output revealed that items 14, 32, and 33, exhibited poor correlation with the scale, as indicated by *r.drop* values below 0.3 [67]. These five items were closely examined and eventually dropped before Cronbach's α was recomputed for the resulting 41-item and 8-factor instrument (version 2). The results revealed an improved Cronbach's α for "Attitude" and "Motivation," but a decrease Cronbach's α for "Learning Methods" and "Learning Activities." Other constructs remained unchanged. Notably, in this iteration, none of the *r.drop* values were below 0.3. The Cronbach's α for "Learning Methods" and "Learning Activities" remaining below 0.70 in the second iteration is an indication of poor reliability of these constructs.

Table 4. Reliability of SRSSDL after two iterations of Cronbach's alpha computation

	Version 1		**Version 2**	
Constructs	**Items**	**Cronbach's α**	**Items**	**Cronbach's α**
Awareness	1-8	0.78	1-8	0.78
Attitude	9-16	0.71	9-13,16	0.73
Motivation	17-22	0.62*	18-22	0.72
Learning Strategies	23-28	0.74	23-28	0.74
Learning Methods	29-35	0.61*	29-31, 34	0.59*
Learning Activities	36-40	0.66*	36-40	0.64*
Interpersonal Skills	41-44	0.71	41-44	0.71
Constructing Knowledge	45-46	0.81	45-46	0.81

* Cronbach's α < 0.7 acceptable criteria

2. Content Validity

Content validity of the SRSSDL was investigated through experts' review. Although the focus of this study was to provide evidence of validity of the SRSSDL without modifying its initial design, the review process necessitated modification of the scale to reflect the engineering context of this study. The experts who conducted the review were three professors in engineering with five to thirty years of experience in engineering education research. One of the experts had substantial expertise on self-regulated learning and self-directed learning; and conducted research in these subject areas. The other two professors contributed their expertise as instructors of engineering courses with interest in building SDL skills in their students. All the experts have various research interests and experience with educational assessment instruments. The experts' review entailed discussing each item with one another, rewording, and separating some items to ensure that the items were clear and would be easily understood by the participants. The consensus reached by the experts led to the creation of the 46-item instrument with an additional four items included for quality assurance (Appendix A).

3. Response Process

Quality checks responses and exclusion of same responses to survey items was done to ensure fitness of the students' responses to the SRSSDL items and construct.

a) Quality check responses

To show evidence of validity through the response process, students were required to provide the correct responses to four quality check items in the SRSSDL instrument. Mismatches in a student's response to the required selection of "Always," "Often," "Seldom," and "Never" were flagged. Such data entry was considered unreliable and was subsequently excluded from the data analysis.

b) Exclusion of similar responses

In addition to quality check, each student's responses were analyzed for similar ratings across all 46 items and across items within the same construct. Data entries from students that provided the same responses to 40 or more items were earmarked for exclusion from data analysis. For the second category, no data entry was excluded because individual review of each construct suggested the data were reliable. These processes were done to ensure credibility of students' responses and of the data analyzed.

4. Relationship with other Variables

Relationship with other variables was investigated by comparing the SRSSDL scores in this study with the SDLR scores in the study by Yuan et al. [63]. In [63], out of a total score of 200, a mean score greater than 150 indicated a high level of self-directed learning, while a low level of SDL was indicated by a mean score less than and equal to 150. In this study, a reverse interpretation applied i.e., high level to moderate level of self-directed learning was indicated by a mean score between 60 and 140 while a low level of self-directed learning was indicated by a mean score above 140. This is because the SRSSDL had a reverse SDLR scale rating.

In Yuan et al. [63], it was expected that senior students have higher SDLR scores than junior students, indicating a maturation process of developing self-directedness. In this study, the same outcome is hypothesized. However, upon comparison of the two results, Yuan et al.'s study [63] revealed that fifth-year nursing students indicated the highest level of SDL, while in the current study, third-year engineering students showed the highest level of SDL. Although a comparable level of SDL was observed for fourth year students in both studies (Table 5), a poor correlation between the two scales can be deduced from the results. Confounding factors (e.g., low sample size, mixing of data from different engineering degree programs, end-of-semester representation of students completing the survey) may be responsible for the differences observed.

Table 5. Comparison of the average SDL scores for students using different SDL scales.

Academic Level	**SRSSDL Score (Engineering)**		**SDLR Score (Nursing) [63]**	
	n = 111	Mean (SD)	n = 485	Mean (SD)
First year	34	104.00 (19.52)	109	154.15 (14.99)
Second year	12	109.25 (18.92)	131	153.55 (14.86)
Third year	37	96.97 (17.72)	115	153.16 (14.46)
Fourth year	22	101.09 (14.93)	102	154.76 (14.88)
Fifth year	6	108.83 (10.32)	28	168.84 (13.43)

5. Consequence of Testing

To show the consequence of the SRSSDL instrument for assessment, a description of its benefits or harm to participants of this study is provided. In all four courses involved in this study, a completion grade with weight less than 1% of the overall course grade was assigned to students that completed the SRSSDL instrument. As per IRB, instructors did not have access to individual student's SDL data, but aggregate results of students' SDL skills in each course were provided to them in a report. The report could have helped instructors to better understand their students and think about their instruction. Students were also made aware of how their SDL data would be used to minimize feelings that their individual responses would have personal consequences. On the benefit side, the instrument may have given students ideas about strategies they employed to help improve their learning.

IV. Discussion

The purpose of this study was to gather validity evidence for SRSSDL in an engineering education setting. The results of CFA and Cronbach's alpha computation were evidence of internal structure validity. The CFA results suggested that Cadorin et al.'s [21] 8-factor SRSSDL model is a poor fit. It does not fully capture the relationships among the variables in the SDL data for the engineering education setting. Regarding internal consistency, the Cronbach's α scores suggested poor instrument reliability as some constructs fell short of meeting the reliability criteria. These results suggest that some items may not accurately represent the construct being measured.

Factors contributing to low internal structure validity may include unclear item wording or the overlapping of items under multiple constructs. Moreover, the inconsistencies observed in the SRSSDL may also be an indication of weak alignment of its items or factor to SDL theory. Furthermore, the assumption that the factors of the SRSSDL instrument are independent of one another is a deviation from the idea of SDL as an iterative and connected process. That means disaggregating the factors may have also contributed to the low internal structure validity of the SRSSDL instrument.

For the response process, potential sources of bias were identified during instrument modification, data collection, and data analysis. Some sources of bias were addressed by removing data entries that met the exclusion criteria and by dropping items to improve the Cronbach's alpha (reliability) of two constructs of the SRSSDL.

The discussion so far underscored concerns expressed by Behar-Horenstein [49] that the SRSSDL instrument “does not identify the same constructs as the original Williamson SRSSDL or the Cadorin and colleagues’ study” [p. 286], confirming that the SRSSDL is inconsistent in a different setting.

For evidence of relationship with other variables, scores from the SRSSDL instrument weakly correlated with scores from the SDLR [63]. This suggests that while both instruments assess self-directed learning, they may emphasize different aspects within a broad construct. The evidence of the consequence of testing with the SDL instrument suggests benefits to the participants in identifying areas of strength and weakness, allowing them to focus on strategies for improving their learning.

V. Limitations

In this study, two major limitations were present that may have impacted the results. First, there was minimal modification to the SRSSDL, potentially resulting in an instrument that may not comprehensively reflect and examine SDL skills in the engineering education context. However, the expert review process helped make the SRSSDL usable and ensured that its original design is retained for validity evidence gathering in the engineering education setting.

Second, the participants in this study were from two departments in a university, constituting a small sample of engineering students in the United States. Consequently, the data collected, and the results obtained may not be an accurate depiction of SDL skills within the broader engineering undergraduate student population.

VI. Recommendations on using SRSSDL in an Engineering Classroom

Self-directed learning skills are essential skills for engineering students. Despite the limitations of the SRSSDL highlighted by this study, new instructors may gain valuable insights about students’ self-directed learning through the instrument. For example, if a student responded “Seldom” or “Never” to being able to identify their areas of strength and weakness, the instructor might consider a one-on-one conversation with the student to learn more about the issue. Providing the student with an opportunity to reflect on an instructor’s assessment and feedback may help the student to transform the knowledge of their strengths and weaknesses into habits that can lead to better academic performance.

Some other classroom approaches that could help new engineering educators foster SDL skills in students are:

Providing clear learning objectives. Clearly articulated learning objectives or course outcomes can help students understand course expectations. When students understand what is expected of them in a course, they are empowered to take ownership of their learning journey and recognize when and where they are falling behind in their learning. Through a curriculum that is aligned with the course’s learning objectives, instructors can foster SDL skills such as autonomy, self-reflection, and problem solving in their students [30]-[68].

Encouraging goal setting. New educators can also guide their students in setting and meeting learning goals through the curriculum's design. This approach would guide students in breaking down tasks or coursework into smaller and manageable parts. Thus, motivating them to build their strengths, improve their weaknesses and follow through on their tasks to completion [30].

Facilitating reflective practices: Integrating reflection activities in engineering curriculum can be helpful in building students' SDL skills. Through reflection, students can notice what they did well and what they could have done better in their homework. Reflections coupled with the instructor's constructive feedback can help students approach tasks in better ways [31]-[68].

Promoting collaborative learning: SDL skills can be cultivated in students by fostering a collaborative environment. Through group activities, interpersonal skills and problem-solving skills can be fostered among students. Engaging with peers can also help students explore things about which they are curious and seek help towards addressing learning challenges.

VII. Conclusion

This paper reviewed scales for evaluating students' self-directed learning skills across various disciplines and highlighted issues with these scales. This study's purpose was to investigate the validity of the Self-Rating Scale of Self-Directed Learning in engineering education and to report evidence of its validity in accordance with contemporary validity framework. The evidence of internal structure validity revealed inconsistencies that indicated that the SRSSDL constructs tended to vary depending on the research context or education setting in which it was implemented. Two constructs of the SRSSDL particularly exhibited low internal consistency. This research corroborates prior research suggesting that SRSSDL exhibits instability. To this end, this study concludes that the SRSSDL may not be suitable for engineering education without significant modifications to enhance its utility, validity, and its alignment with the theory of self-directed learning.

VIII. Future Work

The current research has established the groundwork for a future study to explore self-directed learning (SDL) assessment tailored specifically for engineering education. Such work would entail meticulous examination of literature to better define the dimensions of self-directed learning. This future work would also entail SDL item development and an extensive expert review process to align the items to the theory of self-directed learning. The forthcoming study would also involve a larger and more diverse pool of participants. Through this work, the research team aims to develop a free, valid, and reliable SDL instrument that can be used as a tool to accurately assess SDL skills in engineering students. This tool will greatly support other interventions and strategies to foster SDL skills development in engineering students.

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Appendix A

Table 6. Original and Modified SRSSDL instrument

Factor/Item No.	Original Item Wording [21]	Revised Item Wording
Awareness		
1	I identify my learning needs	I identify my learning needs
2	I am able to select the most suitable method for my learning	I am able to select the most suitable learning strategies to aid my learning
3	I keep up to date with the range of learning resources available	I keep up to date with new learning resources
4	I am responsible for my learning process	I am responsible for my learning process
5	I am responsible for identifying the areas I need training in	I am responsible for identifying the areas in which I need to improve my learning
6	I am able to maintain my motivation for learning over time	I am able to maintain my motivation for learning over time
7	I am able to plan and define my learning goals	I am able to define my learning goals
8		I am able to make a plan to meet my learning goals
Attitude		
9	I maintain good interpersonal relationships with others	I maintain good interpersonal relationships with others
10	My verbal communication is effective	My verbal communication is effective
11	I find it easy to work in collaboration with others	I find it easy to work in collaboration with others
12	I am able to express my ideas freely	I am able to express my ideas freely
13	I find it necessary to create interdisciplinary relations in order to maintain social harmony	I find making connections between what I am learning, and other disciplines improves my learning
14	I am able to express my ideas effectively in writing	I am able to express my ideas effectively in writing
15	I appreciate any criticism as a basis for improving my learning	I appreciate any criticism as a basis for improving my learning
16	I keep an open mind to points of view different from my own	I keep an open mind to points of view different from my own
Motivation		
17	New learning is challenging for me	New learning is challenging for me
18	I consider problems as challenges	I consider problems as challenges
19	I am motivated by other people's success	I am motivated by other people's success

Factor/Item No.	Original Item Wording [21]	Revised Item Wording
20	I organize my self-learning activities in order to develop an ongoing learning approach in my life	I organize my self-learning activities in order to develop an ongoing learning approach in my life
21	I make use of any opportunities that come my way	I explore opportunities to enhance my learning strategies
22	I am internally motivated to develop and improve my learning method	I am internally motivated to develop and improve my learning method
Learning strategies		
23	I am able to identify my areas of strength and weakness	I am able to identify my areas of strength
24		I am able to identify my areas of weakness
25	I am able to assess my learning progress	I am able to assess my learning progress
26	I am able to assess the achievement of my learning objectives	I am able to assess the achievement of my learning objectives
27	I am able to identify my learning strategies	I am able to identify my learning strategies
28	I am able to define my role within a group	I am able to define my role within a group
Learning methods		
29	I make notes or summarise all my ideas, thoughts, and new learning	I note or summarize my ideas/thoughts about new things I am learning
30	I enjoy exploring information even beyond the prescribed aims of a course	I enjoy exploring information even beyond the prescribed aims of a course
31	My concentration and my attention increase when I read a complex study content	My concentration increases when I work on complex material
32	I go back over and revise my new lessons	I go back over and revise my class notes
33		I think that revisiting new concepts multiple times is an effective learning technique
34		I think reflection on my learning is an effective learning technique
35		I think teaching my peers a concept is an effective learning technique
Learning activities		
36	I think simulation is an effective didactic technique	I think simulation is an effective learning technique
37	I think case studies are an effective didactic technique	I think relating concepts to real-world examples is an effective learning technique

Factor/Item No.	Original Item Wording [21]	Revised Item Wording
38	I find interactive didactic sessions are more effective than listening to lectures	I find interactive learning is more effective than listening to lectures
39	I find role play is a useful technique for complex learning	I think project work is an effective learning technique
40		I think working with peers is an effective learning technique
Interpersonal skills		
41	I take part in group discussions	I take part in group discussions
42	I feel the need to share information with others	I feel the need to share information with others
43	I find the support of my peers very effective	I find the support of my peers very effective
44	My interaction with others helps me develop my programme of further learning	My interaction with others helps me develop a plan for further learning
Constructing knowledge		
45	I think conceptual maps are an effective didactic technique	I think conceptual maps are an effective learning strategy
46	I use the conceptual map as a useful method for understanding a wide range of information	I use conceptual maps to understand a wide range of information