WIP: Comparative Analysis of Instructional Methods Based on Competences

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***Abstract*—Computing and engineering educators often adopt various instructional methods, e.g., flipped classroom and project-based learning, to facilitate the teaching and learning process. Extant literature has analyzed the benefits and demerits of these instructional methods. Moreover, there are considerable amount of literature that have proposed a set of professional competences required by employers in engineering and computing professions. Currently, there is paucity studies that have investigated the instructional methods that best support the delivery and acquisition of core professional competences by instructors and students respectively. This creates a gap in literature and leave some research questions unanswered. For instance, which instructional methods best support instructors to deliver professional competences such as problem solving, teamwork and critical thinking? On the other hand, which instructional methods best enable students to acquire professional competences? The aim of this on-going research is to report the progress we have made in our attempt to close this gap, answer this research question, and thus contribute to knowledge. Accordingly, we present a set of instructional methods and professional competences in computing and engineering as identified from extensive literature. Secondly, we discuss the Randomized Block Factorial Design (RBF) which we intend to use for validating our hypothesis. We also, presented our hypothesis and research question. Finally, we discuss our data collection strategy, research instrument and its validation. We intend to perform a rigorous data analysis and report the complete research in our future.**

Keywords—competences, instructional methods, skills, teaching methods, pedagogical approaches *(key words)*

I. Introduction

One major aim of most academic programs and courses , in universities and colleges, is to help students acquire core competences relevant to their career and professional success [1]. Building on existing studies[1, 2], we define competences as a set of skills, knowledge and dispositions required for career success in a given profession. The delivery and acquisition of professional competences involve a collaborative effort between the instructor, who is the subject matter expert and the students who are the learners. Instructors usually derive competences from variety of sources such as accrediting or licensing organizations e.g., ABET and analysis of job descriptions. Competences are also derived through feedback from recruiters, employers and industry collaborators. Some examples of competences in computing and engineering profession include teamwork, problem solving, critical thinking, systems design and communication [1, 2] etc. In order to deliver these competences to students, instructors normally adopt and use one or more instructional methods.

Currently, a variety of instructional methods are available and commonly used in computing and engineering education. For clarity, we define instructional method as any technique or procedure used by instructors and students to deliver and acquire competences respectively [3]. Examples of popular instructional methods used to teach computing and engineering courses include project-based learning[4], [5] and its variant known as cross-course project-based learning [6]. Others include game-based learning [7], [8], flipped classroom [9], [10], and direct instruction[9]. Instructors who implement these instructional methods report various benefits, including support for student learning, improved academic performance, student engagement and retention, among others [5], [6],[9], [10].

Instructional methods are known to be the major avenues or means for the delivery and acquisition of competences. As evidenced in existing literature[3],[4],[7],[8] each instructional method supports the delivery and acquisition of a different set of competences. For instance, studies[6],[11],[12] have shown repeatedly that competences such as problem-solving, problem identification and teamwork are better delivered to students using project-based learning as the instructional method. Similarly, instructors that implemented game-based learning report that it better facilitates the acquisition of competence such as critical thinking and collaborative skills [7], [8]. In order to derive the full benefits of instructional methods, a comparative framework is needed to help instructors identify and select instructional methods that best support the delivery and acquisition of a particular set of competences. Currently, we cannot find such a framework in current literature. As a result, the current practice in selection of instructional methods is mostly based on trial and error. Moreover, in other cases, the selection of instructional methods is without considerations for the set of competences the selected instructional method can best support. This can hinder the effective delivery and acquisition of competences required by students to be successful in their career and profession.

In order to address the above challenge, this paper performs a comparative analysis of popular instructional methods, used in computing and engineering education, based on the competences they best support. Using the result of our comparative analysis, we intend to contribute a framework that can guide instructors to select instructional method(s) that are appropriate for the delivery and acquisition of a given set of competences. In order words, if an instructor desires to deliver a competence (e.g., systems design) in a given course, our proposed framework is intended to help the instructor to identify and select one or more instructional methods that will be effective to deliver and acquire this competence (i.e. systems design). More so, our framework intends to provide a direct mapping between an instructional method (say flipped classroom) and the set of competences that are best supported by this instructional method. Accordingly, our study will answer the following research question (RQ) and test the hypothesis stated below. Our research hypothesis (RH) builds on existing work done by Zendler et al, see [3], [13]

- ***RQ:*** *Which instructional methods best support the delivery and acquisition of computing and engineering competences?*
- ***RH****: Instructional methods used in computing and engineering education differ in supporting competences*

To answer the above research question and test our hypothesis, we first conducted literature review to identify competences and popular instructional methods in computing and engineering education. Afterwards, we designed a questionnaire using the instructional methods and competences we identified from literature. This questionnaire is used to collect data from students within the computing and engineering discipline. Our intention is to analyze the collected data using 15 x 15 Randomized Block Factorial (RBF) Design similar to the approach used in [3], [13].

However, in this work-in-progress paper, we aim to discuss the progress we have made so far in this research and also presents preliminary results. Accordingly, we present a set of instructional methods and professional competences in computing and engineering as identified from extensive literature. Secondly, we discuss our data collection strategy, research instrument and its validation. We then present preliminary analysis of our collected data. The remainder of this paper is organized as follows: Section 2 provides an abridged version of our literature review and related work. In Section 3, discuss our research methodology, including our data collection. Section 4 shows our preliminary results. In Section 5, we discuss our future work and provide conclusion to our work-in-progress paper.

II. Literature Review

A. Instructional Methods

Instructional methods have been the subject of many pedagogical studies in recent times. As a result, there are a considerable number of publications that focus on instructional methods. Various scholars have made attempts to define instructional methods in various ways. However, for the purpose of this research, we adapt the definitions presented by the authors in [3]. Thus, we define instructional methods as clearly defined and conceptually perceivable procedures or techniques used by instructors and students to respectively deliver and acquire competences [3]. This definition implies that instructional methods must be precisely defined to help instructors deliver competences defined in their learning objectives, and at the same time, helps students to develop and apply those competences.

Although publications that contribute to instructional methods abound in literature, these publications often focus on other aspects of instructional methods. Consequently, the relationship between instructional methods and the competences they best support are often neglected, if considered at all, in extant literature. Most studies, such as[10], [14], [15] appear to focus on comparing and contrasting emerging instructional methods such as cooperative learning and flipped classroom with the traditional direct instruction. Moreover, we found studies evaluating the effectiveness of a given instructional method in both an online and face-to-face environment. Examples of these studies can be found in [16][17][18]. There are also studies that analyze the relative advantages and disadvantages of certain instructional methods with regards to their ability to support student learning and improve academic performance [4], [9], [10]. However, the assessment of learning in these studies are usually based on student grades in projects, assignments and examinations, instead of competences like teamwork, problem-solving and systems design skills.

Our literature review shows that there are over 100 instructional methods [3]. However, for the purpose of our study, we identified 15 instructional methods that meet the following criteria: (a) the instructional method is usable and applicable in computing and engineering education. (b) the instructional method has been implemented by one or more computing and engineering instructors; and (c) the instructional method has been evaluated and reported in a peer-reviewed conference proceedings or journals. The instructional methods identified after applying the above criteria are shown in Table 1.

B. Competences in Computing and Engineering Profession

In recent times, there appears to be growing research interests in the acquisition, development and delivery of professional competences. The idea of competence development in teaching and learning seems to originate from competence-based learning (CBL) also called competence-based education. CBL is a pedagogical method that emphasizes the acquisition, delivery, and assessment of competences as the criteria for learning [1]. Over the years, CBL has proved to be an effective pedagogical method that equips students for career success and is increasingly becoming popular as an alternative to traditional pedagogical methods[1]. While the traditional methods focus on contents and the number of instructional hours completed by learners; CBL is based on learners' ability to acquire and demonstrate professional competences[1].

While research in competence development is currently gaining traction, there are slight differences in the various definition of the term competence in literature. Yet, there appear to be a general consensus that the term competence is made up of three interrelated concepts namely, skills or abilities, knowledge and disposition. Hence, we build on the framework presented in [1], [2] and define competence as the set of skills, knowledge and disposition desired by employers and required for career success in a given profession [1], [2]. The authors in

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[1], [2] further define skill as abilities and capabilities developed through cognitive efforts. Skill can be hard skill such as systems design or soft skill such as teamwork. Knowledge is a set of proficiency or insight of key concepts in a particular profession. Dispositions are personal traits and emotional abilities that helps an individual to perform tasks.

Table 1: Computing and Engineering Instructional Methods

Factor	Instructional Method	Sample Study
a_1	Active Learning	[19]
a_2	Case-based Teaching	[20]
a_3	Collaborative Learning	[21]
a_4	Direct Instruction	[22]
a_5	Flipped Classrooms	[10]
a_6	Game-based Learning	[7]
a_7	Inquiry-based Learning	[23]
a_8	Just-in-time Teaching	[24]
a_9	Pair Programming	[25]
a_{10}	Peer-Instruction	[26]
a_{11}	Recorded Lecture	[27]
a_{12}	Project-based Learning	[6]
a_{13}	Puzzle-based Learning	[28]
a_{14}	Service Learning	[29]
a_{15}	Video-Based Tutorial	[30]

A plethora of competences are available in literature. Usually, competences are discipline or profession specific, although few competences such as teamwork, communication and presentation skills appear to be generic. However, we are interested in computing and engineering specific competences. To identify these competences, we reviewed existing studies that focus on identification and development computing and engineering competences, for example see[1], [31], [32]. We cross-checked the competences identified from literature to ensure that they are consistent with those in ABET.

We selected ABET[1], since it is a leading organization that accredit engineering and computing education programs across the USA. Our selection criteria for competence is similar to the ones we used to select instructional methods, see Section II-B. These are as follows: (a) the competence is specific to computing and engineering profession. (b) the competence closely aligns to one or more skill in ABET Competence Model; and (c) the competence is reported in a peer-reviewed conference proceedings or journals. Overall, we identified 15 competences that match the above criteria. As noted earlier, these are shown in Table 2. These competencies in Table 2 are derived from recent studies that analyzed industry job descriptions advertised in on newspapers and popular job portals such as indeed.com, IEE Job Site, monster.com, careerBuilder.com, idealist.org, and simplyhired.com [1], [31], [32].

Factor	Competences	Type
b_1	Collaborative	Soft Skills
b_2	Teamwork	
b_3	Communication	
b_4	Analyze Problems	Disposition
b_5	Critical Thinking	
b_6	Analytical Ability	
b_7	Creativity/Creative	
b_8	Apply Knowledge	
b_9	Interpersonal skills	Hard Skills
b_{10}	Problem Solving	
b_{11}	Problem identification	
b_{12}	Evaluate Systems	
b_{13}	Systems Design	
b_{14}	Project Management	
b_{15}	Implement Systems	

Table 2: Competences in Computing and Engineering Profession

[1] https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-computing-programs-2018-2019/

Indeed, the current literature in competences development and instructional methods have made considerable contributions. However, it is difficult to find studies that provide a framework to help instructors identify and select instructional methods needed to deliver a set of desired competences. Moreover, there are a paucity of studies that have analyze the relative strengths and weaknesses of instructional methods with respect to the competences they best support. In order to realize the full potentials of instructional methods and enable students to acquire competences required for career success; it would be useful to provide insight into the set of professional competences that are best supported by each instructional method. Unfortunately, studies that consider these are rarely available.

Although, professional competencies can be acquired both school through instruction and on the job through practice. We currently focus our attention on the competencies developed through instructional methods in higher education. This study aims to close the current gap through a comparative analysis of instructional methods based on competence criteria. We plan to use the result of our analysis to develop a framework that maps each instructional method to a set of competences that it best support.

III. RESEARCH METHOD

In this section we discuss our data collection and analysis approach. We also present the demographic data collected from our respondents.

A. Data Collection.

In order to answer our research question and make the desired contributions, we collected quantitative data. Our data collection is by means of a survey designed in Survey Monkey Software. The first part of our survey contains demographic information of participants such as program of study, age, and level of study. In the second of part of our questionnaire, we listed the instructional methods in Table 1 in our questionnaire and asked students to select instructional methods that their instructors have used to teach them or the instructional methods they have knowledge of. Then the following question listed the competences in Table 2 and asked them rank (in a 5-point Likert Scale) how helpful the instructional methods they selected in previous question helped them acquire and develop each competence. After designing our questionnaire, we conducted pilot study before distributing the questionnaire to students. Our target participants were computing and engineering students in a university in Northern Pennsylvania, USA. We received a total of 271 (two hundred and seventy-one) responses.

The demographic data of our responses is shown in figures 1, 2 and 3. Figure 1 shows the percentage of responses we received by the level of studies of respondents. The respondents are roughly 50 percent undergraduate and 50 percent graduate students. Similarly, Figure 2 shows both the age group and ethnicity of our respondents. Approximately, 46 percent of our respondents are Generation Z students i.e., students born between 1995 and 2012. The approximate percentage of millennials (students born between 1980 and 1994) that responded to our questionnaire is 51. The remaining 3 percent are students born before 1980. Figure 3 shows the majors or

ANSWER CHOICES	RESPONSES	
Undergraduate freshmen	12.18%	33
Undergraduate sophomore	11.07%	30
Undergraduate junior	12.18%	33
Undergraduate senior	15.13%	41
Graduate enrolled in master program	39.85%	108
Graduate enrolled in PHD program	9.59%	26
TOTAL		271

Figure 1: Respondents' Level of Study

ANSWER CHOICES	RESPONSES	
18-21	15.87%	43
22-25	29.89%	81
26-29	23.25%	63
30-33	14.39%	39
34-37	8.12%	22
38-41	5.17%	14
42 and above	3.32%	9
TOTAL		271

ANSWER CHOICES	RESPONSES	
White or Caucasian	24.35%	66
African American	8.49%	23
Hispanic or Latino	8.49%	23
Asian or Asian American	24.72%	67
American Indian or Alaska Native	5.54%	15
Native Hawaiian or other Pacific Islander	5.54%	15
Another race	22.88%	62
TOTAL		271

Figure 2: Respondents' Age and Ethnicity

ANSWER CHOICES	RESPONSES	
Information Technology	12.18%	33
Information Systems	2.58%	7
Management Information Systems	3.32%	9
Data science	9.23%	25
Information Analytics	5.17%	14
Electrical engineering	5.90%	16
Software engineering	6.64%	18
Engineering management	3.32%	9
Mechanical engineering	7.75%	21
Industrial Engineering	1.85%	5
Computer Engineering	5.54%	15
Cyber Security	4.06%	11
Aerospace and Aeronautical Engineering	1.85%	5
Biomedical Engineering	7.01%	19
Chemical Engineering	1.48%	4
Civil Engineering	2.21%	6
Environment Engineering	0.74%	2
Agricultural Engineering	1.48%	4
Audio Engineering	0.74%	2
Automotive Engineering	0.37%	1
Materials Science Engineering	1.11%	3
Mining and Geological Engineering	1.11%	3
Nuclear Engineering	0.37%	1
Petroleum Engineering	1.48%	4
Electrical & Computer Engineering	1.48%	4
Cyber Risk Management	0.37%	1
Cyber Engineering	2.21%	6
Undecided Engineering	2.21%	6
Undecided Computing	1.48%	4
Environment Health and Engineering	3.32%	9
Embedded Software Engineering	1.48%	4
TOTAL		271

Figure 3: Respondents Major or Academic Programs

academic programs of respondents. This figure shows that all academic programs and majors are either computing or engineering discipline.

B. Plan for Data Analysis .

Our plan for data analysis include designing a 15 x 15 Randomized Block Factorial (RBF) Experiment Design[3], [13], see Figure 4. The dependent variables are Factor A and B. Factor A ($a_1....a_{15}$) contains the 15 instructional methods we identified from our literature review, See Table 1; while Factor B ($b_1....b_{15}$), contains the 15 competences we identified and presented in Table 2. The independent variables are the respondents' ratings of the instructional methods based on student perception of their helpfulness in acquiring competences. Unlike the work done in [3], [13], we used a 5-point Likert Scale from Extremely Helpful (5) to Not Helpful At All (0).

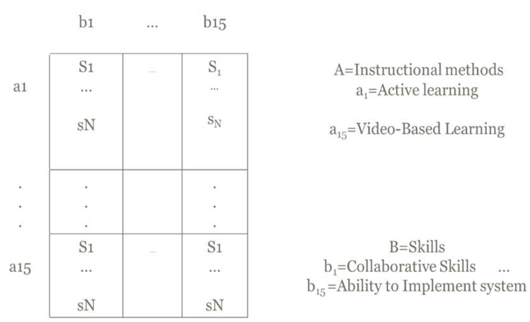

Figure 4: Our 15x15 RBF Design Model

We plan to adopt the procedure recommended by similar studies [3], [13] for analyzing data in an RBF Experiment Design. Accordingly, we will use a 2-Factor ANOVA (Analysis of Variance) with repeated measures to consistent with a 15 x 15 RBF Experiment. In order to identify the instructional methods that best support a set of competences, we will complement the 2-Factor ANOVA with a Cluster Analysis. Our intention is to use statistical tools such as R, JASP or JAMOVI to support our data analysis.

IV. CONCLUSION AND FUTURE WORK

This work-in-progress paper presents an ongoing research aimed to contribute a framework to help computing and engineering instructors identify and select appropriate instructional methods to best support the delivery of desired competences. Currently, we cannot find a similar framework in extant pedagogical research. Building on related research, we hypothesize that instructional methods used in computing and engineering education differ in their capability to support the delivery and acquisition of competences. We believe that there should be a mapping between an instructional method and a set of the competences it can support. We wanted to report the progress we have made in this research and encourage other researchers to engage in related studies. In this regard, we present a set of instructional methods identified used in computing and engineering, and present the criteria we used to selected them, see Table 1 and Section II-A. Also, in Table 2, Section II-B, we present a list of competences in computing and engineering profession, and categorized them into soft skills, disposition and hard skills. Furthermore, discuss our data collection and analysis strategy, including our RBF Experiment Design. Finally, we present the demographic information of our from our data collection.

Once we have identified the institutional method that will advance a given competency, we will be able to indentify the most efficient instructional method to cover the most desired competencies using the same instructional method. Further, we will be able to identify efficient instructional methods for specific competencies. However, future research will be needed in order to determine the most effective and efficient instructional methods to cover the desired competencies.

We intend to complete this research soon and report contribution as a full paper in future conferences and journals. This will be achieved using the statisitical approach we discussed in Section III-B, which include 2-Factor Analysis of Variance (ANOVA) and Cluster Analysis. Then, we plan to use the results of these data analysis to contribute a framework that can relate each instructuctional method to the competences it can support.

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