An Approach to Measure Innovation and Entrepreneurship Fostering of a Curriculum by Using ABET Assessment Data

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***Abstract*— This Research-to-Practice Full-Paper attempts to provide a quantitative method to measure a curriculum's inherent innovation and entrepreneurship through available assessment data. This paper builds on our previous works relating systems thinking and design methodology to innovation and entrepreneurship. In this work, we try to reduce the complexity associated with innovation by presenting it as a function of "innovativeness" characteristics. This approach will use the student outcome assessment data compiled for the ABET accreditation process and obtain a measure of the innovativeness and entrepreneurship of the curriculum. The proposed scheme also reveals the usefulness of the data beyond the accreditation process. Given the nature of the collected data, the proposed approach cannot be used to compare programs, and it is only a self-assessment indicator. The paper contains examples that show complete innovation and entrepreneurship calculations for an engineering program. Institutions can use the proposed approach to further assess their curriculum's effectiveness and identify the necessary changes to advance innovation and entrepreneurship.**

Keywords—Innovation, Entrepreneurship, Assessment, ABET.

I. Introduction

Innovation is an integral part of human existence and history. Innovation has been recognized as an essential component of advancements and modernization. For example, Drucker [1] showed that innovation had been the leading source of job creation in the United States over the last century.

There is no consensus on the definition of innovation and entrepreneurship among scholars [2]. A review of published works regarding innovation provides a general definition as the development and use of new ideas or behaviors in organizations manifested in terms of a new product, service, or method of production or a new market, organizational structure, or administrative system [3].

Similarly, there is no common definition of the term “entrepreneurship” either (e.g., [4]). From the literature search, it appears that Schumpeter [5] was the first to stress the critical role of entrepreneurship in the economy and society. His “process of creative destruction” articulates the activities of entrepreneurs for change. Gunderson [6] is of the opinion that entrepreneurship is a process of small incremental innovation as opposed to making a giant leap forward and sees an entrepreneur as being very focused, seeing what others have overlooked. In our previous work [7], we categorized the work in this area into four groups. The first group covered general academic features and requirements; the second group covered specific characteristics associated with entrepreneurship; the third group covered entrepreneurship mindset, and the fourth group included the curriculum delivery as its focus.

Promoting innovation and entrepreneurship has received much attention, in recent years, by mainly focusing on associated characteristics and their assessment. Identifying the characteristics that are associated with innovation, essential traits of engineering innovativeness, and corresponding skills and behavior will enable us to provide feedback to students and practitioners, which will allow us to inform them about the innovative skills they can improve upon, as well as characteristics that cannot be changed or easily changed (e.g. [9]-[19]). Entrepreneurial attributes are characteristics that motivate and enable individuals to begin the challenging process of creating new ventures (e.g. [20]-[22]). These personal traits highly influence entrepreneurs’ performance and success at different stages of the entrepreneurship process [23]-[26].

Section II presents our current work, extending our previous work in this area [27]. In [27], we proposed mapping the innovative characteristics [13] to the current ABET [29] student outcomes. In this work, we will present two complete examples that calculate the innovativeness and entrepreneurship of a program using the suggested impact factors. We also extend the results by calculating the factors that the program is fostering individual innovativeness characteristics. The idea is to obtain a more objective measure of the program's innovativeness that can be used for future improvements. Due to the nature of the assessment data, the calculated number is a self-assessment program indicator and provides a measure of innovativeness achievement (IA) for students for the cycle that the ABET data were collected. The paper concludes with a short discussion about the suggested model and future work in this area.

II. Proposed Approach to Measure Innovativeness and Entrepreneurship

In [28], we presented a summary of works that can help us understand innovation, its associated characteristics, and attributes and investigate its relationship with engineering design. In this work, we only present a summary of results related to innovativeness characteristics.

Purzer et al. in [30] have identified five critical characteristics of an engineering innovator: deep knowledge, active learner/curious, vision/caring, team manager/leader, and risk-taker. Menold et al. in [31] have examined innovativeness assessment and analyzed ten measures and models of innovativeness through two lenses: (i) their attributes vs. actions and (ii) their relationship to cognitive level, style, and effect. The authors concluded that a comprehensive, rigorously validated psychometric instrument does not yet exist to assess the aptitudes, skills, knowledge, personality traits, and behaviors that are indicative of an innovative engineer. They present their five-year study in a table (Table 1 in [13]) and identify twenty characteristics related to innovative behavior, capturing a significant number of innovation characteristics suggested in various papers. We have used this paper in our previous works. We believe one way to understand innovation is to study innovativeness characteristics, and innovation can be promoted by fostering those characteristics. This is the approach that we suggested in our previous work [28], but as we pointed out, more work needs to be done in this area.

Innovativeness characteristics only provide us with the components that make up innovation but not their required combination. The exact combination needed differs for each individual and rests on many factors such as background, environment, etc. Hunter et al. [35] also recognizes this and characterizes it as "contextual moderators," which include factors such as climate, rewards, recognition, and resources. Therefore, we can only talk about the mix in general terms, such as being "creative" has a higher impact than being a "developer" in becoming an innovator. The more we know about the "required" combination, the more accurate our development will become, and this is the key requirement in our proposed approach. Therefore, in our previous work [27], we proposed a ranking version of Table 1 in [13]. Table 1 [27] presents our proposed mapping that will be used in followed examples.

TABLE 1: INNOVATIVENESS MEASUREMENT - CHARACTERISTICS' IMPACT FACTORS & ABET MAPPING

Characteristic	Impact Factor	Related ABET Student Outcomes
Alternatives Seeker	0.85	1, 2, 4
Analytical	0.75	1, 2, 6
Associative Thinker	0.80	1, 2, 4, 6
Challenger	0.65	2, 6
Collaborator	0.50	2, 3, 5
Communicator	0.20	2, 3, 5
Creative	1.00	1, 2, 4, 6
Curious	0.90	1, 6, 7
Developer	0.55	1, 2, 5, 6
Experimenter	0.45	2, 6
Implementer	0.40	5, 6
Knowledgeable	0.70	1, 2, 4, 6, 7
Leader	0.15	2, 5
Market/Business Savvy	0.05	4, 6
Passionate	0.30	2, 4, 5
Persistent	0.60	1, 2, 6
Risk Taker	0.35	6
Self-Reliant	0.25	1, 6, 7
User Empathetic	0.10	2, 4
Visionary	0.95	2, 4, 6

The innovativeness calculation will be based on using student outcomes evaluations calculated by applying the associated performance indicators (PIs). The reason behind using the assessment data is due to the availability of the information and, therefore, not requiring additional resources to start the process. We acknowledge that further studies focusing on each innovativeness characteristics would benefit the proposed method, but it will also come with a price tag that most institutions cannot afford. We also emphasize that the (current) proposed evaluation using the available information provides additional insight into innovation and entrepreneurship that have not been explored before. To illustrate the process, we will start with a brief introduction to the ABET assessment process. Table 2 shows the innovativeness measurement table adjusted for entrepreneurship calculation.

TABLE 2: ENTREPRENEURSHIP MEASUREMENT - CHARACTERISTICS' IMPACT FACTORS & ABET MAPPING

Characteristic	Impact Factor	Related ABET Student Outcomes
Alternatives Seeker	0.70	1, 2, 4
Analytical	0.05	1, 2, 6
Associative Thinker	0.25	1, 2, 4, 6
Challenger	0.15	2, 6
Collaborator	0.75	2, 3, 5
Communicator	0.80	2, 3, 5
Creative	1.00	1, 2, 4, 6
Curious	0.30	1, 6, 7
Developer	0.20	1, 2, 5, 6
Experimenter	0.85	2, 6
Implementer	0.10	5, 6
Knowledgeable	0.70	1, 2, 4, 6, 7

Leader	0.35	2, 5
Market/Business Savvy	0.95	4, 6
Passionate	0.45	2, 4, 5
Persistent	0.60	1, 2, 6
Risk Taker	0.50	6
Self-Reliant	0.40	1, 6, 7
User Empathetic	0.55	2, 4
Visionary	0.9	2, 4, 6

III. ABET CRITERIA FOR ACCREDITING ENGINEERING PROGRAMS: CRITERION 3 (STUDENT OUTCOMES) AN CRITERION 4 (CONTINUOUS IMPROVEMENT)

All programs seeking accreditation from the Engineering Accreditation Commission of ABET must demonstrate that they satisfy all of the General Criteria for Baccalaureate Level Programs. For this work, we need the data gathered by a program to satisfy Criterion 3 (student outcomes) and our presented under Criterion 4 (continuous improvement). The ABET's explanation for criterion 3 and criterion 4 is given below. The information has been copied from ABET's 2021-2022 Criteria for accrediting engineering programs document [29].

Criterion 3. Student Outcomes

The program must have documented student outcomes that support the program educational objectives. Attainment of these outcomes prepares graduates to enter the professional practice of engineering. Student outcomes are outcomes (1) through (7), plus any additional outcomes that may be articulated by the program.

1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors
3. an ability to communicate effectively with a range of audiences
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies

Criterion 4. Continuous Improvement

The program must regularly use appropriate, documented processes for assessing and evaluating the extent to which the student outcomes are being attained. The results of these evaluations must be systematically utilized as input for the program's continuous improvement actions. Other available information may also be used to assist in the continuous improvement of the program.

It should be noted that assessing the student outcome involves designing appropriate performance indicators and rubrics for each outcome. Programs also choose a "level of achievement" for the outcomes. For example, the following plot, see Fig. 1, summarizes student results for outcome one for a program. Three performance indicators were constructed for this outcome, and related student performances were assessed. The plot also shows 80% as the target, meaning that an assessment result below that level indicates that the outcome has not been met an improvement action is required.

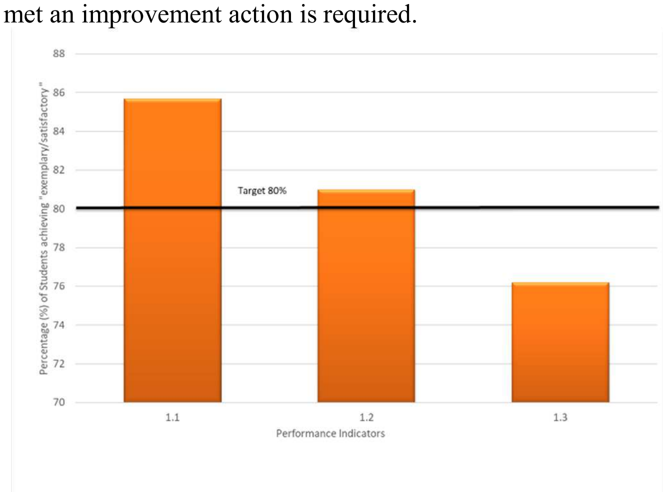

Fig. 1: Summary of student Outcome 1 (average = 81%)

IV. PROPOSED CALCULATION TO MEASURE INNOVATIVENESS AND ENTREPRENEURSHIP

The proposed calculation is based on utilizing the impact factor and using the data from the ABET assessment related to the identified performance indicators as shown below:

$$C_i = f\left(O_{j=1,\ldots,7}\right), \quad i = 1, \ldots, 20 \tag{1}$$

$$(IA)_{upper} = (IF)_i * Max\left(O_{j=1\ldots 7}\left(E[PIs]\right)\right), i = 1, \ldots, 20 \tag{2}$$

$$(IA)_{lower} = (IF)_i * Min\left(O_{j=1,\ldots,7}\left(E[PIs]\right)\right), i = 1, \ldots, 20 \tag{3}$$

$$(IA)_{cycle} = \left((IA)_{upper} + (IA)_{lower}\right)/2 \tag{4}$$

$$IM = \left(\sum_{cycle=1}^{cycle=3}(IA)_{cycle}\right)/3 \tag{5}$$

Where, C_i means the i^{th} entry in Table 1 (or Table 2); O_j means calculation is related to ABET's Student Outcome j; $O_j(E[PIs])$ means the average of performance indicators that are defined for the j^{th} Outcome, $(IF)_i$ means impact factor related to the i^{th} entry in Table 1 (or Table 2), $(IA)_{upper}$ means the maximum Innovation (or entrepreneurship) achievement, $(IA)_{lower}$ means the minimum Innovation (or entrepreneurship) achievement, and *IM* means Innovativeness measure. The $(IA)_{cycle}$ represents the Innovation achievement, based on one-cycle data, calculated as the average of the upper and lower limits, as shown in equation (4). This calculation is consistent with a typical outcome assessment calculation used in ABET.

For example, looking at "analytical" characteristic, which has the following assigned impact factor and student outcome associations.

TABLE 3: IMPACT FACTOR & ABET MAPPING FOR "ANALYTICAL" CHARACTERISTIC

Characteristic	Impact Factor	Related ABET Student Outcomes
Analytical	0.75	1, 2, 6

We will have the following equations for the upper or lower innovation (or entrepreneurship) calculations.

$$Analytical \triangleq C_2 = f(O_1, O_2, O_6)$$
$$(IA)_{upper} = (IF)_i * Max(O_1(E[PIs]), O_2(E[PIs]), O_6(E[PIs])$$
$$(IA)_{lower} = (IF)_i * Min(O_1(E[PIs]), O_2(E[PIs]), O_6(E[PIs])$$

The proposed calculation aims to present a straightforward way to quantify a popular concept, which does not have any associated tool for its measurement. It follows the similar methodology we use to understand and solve problems. Namely, if you have a complex problem (or compound) composed of many components, the first step is to identify the parts and then identify the relationship between them. This will provide the structure. In this work, we indicate that Innovation (or Entrepreneurship) is a complex phenomenon composed of twenty components (characteristics). The impact factor presents the proposed ideal amount of each element. Here we used fractions instead of whole numbers to identify the ideal amount of each component (characteristics). The structure of the equations is similar to other methods that include weighting factors in determining an outcome.

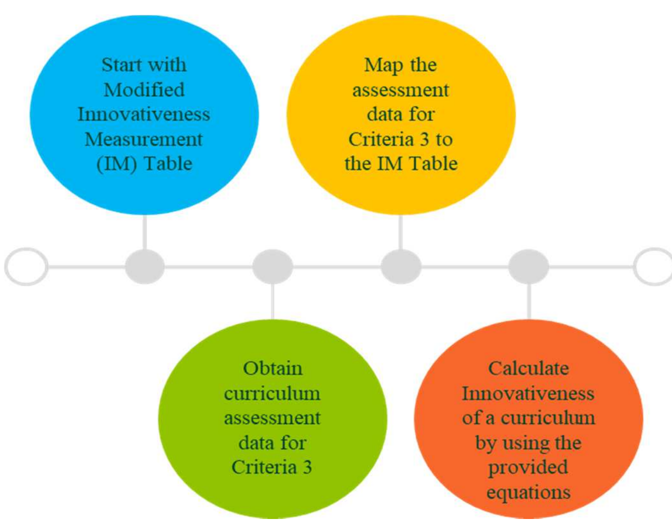

Fig. 2: Innovation Calculation Steps

V. EXAMPLES

Next, we will look at the performance indicators for the student outcome results related to a complete data set, see Table 4, and calculate the upper and lower innovation and entrepreneurship calculations. The calculation will consider the 80% target number set by the program. The sample data provided in Table 4 will be used throughout this paper. The seven ABET student outcomes have different numbers of PIs. The "Result" column reflects the score for each PI based on the collected evidence by the program, such as homework, quizzes, exams, and presentations. The average calculation for performance indicators reflects how outcomes are measured in a typical ABET assessment calculation. We used the same approach in constructing our equations.

TABLE 4: SAMPLE DATA FOR ABET CRITERIA 3 ASSESSMENT

Outcome	PI	Result (0-100)	Average (0-100)
1	1.1	80.2	
	1.2	86.8	
	1.3	83.4	**83.5**
2	2.1	74.5	
	2.2	83.7	
	2.3	86	**81.4**
3	3.1	87.8	
	3.2	62.8	
	3.3	56	
	3.4	87.3	**73.5**
4	4.1	69.8	
	4.2	73.1	
	4.3	49.9	**64.3**
5	5.1	82.7	
	5.2	84.2	
	5.3	91.1	**86.0**
6	6.1	73.3	
	6.2	79	
	6.3	73.6	**75.3**
7	7.1	75	
	7.2	60	**67.5**

Using Table 4 data and equations 1-4 we will obtain the following results:

TABLE 5: INNOVATION CALCULATIONS

Upper	Lower	IA Achieved Over One Cycle	80% Target Number	% Deviation
70.9	54.6	62.8	68	-8.3%
62.6	56.5	59.5	60	-0.8%
66.8	51.4	59.1	64	-8.3%
52.9	48.9	50.9	52	-2.1%
43.0	36.7	39.9	40	-0.3%
17.2	14.7	15.9	16	-0.3%
83.5	64.3	73.9	80	-8.3%
75.1	60.8	67.9	72	-6.0%
47.3	41.4	44.4	44	0.8%
36.6	33.9	35.3	36	-2.1%
34.4	30.1	32.3	32	0.8%
58.4	45.0	51.7	56	-8.3%
12.9	12.2	12.6	12	4.4%
3.8	3.2	3.5	4	-14.6%
25.8	19.3	22.5	24	-6.5%
50.1	45.2	47.6	48	-0.8%
26.4	26.4	26.4	28	-6.2%
20.9	16.9	18.9	20	-6.0%
8.1	6.4	7.3	8	-9.8%
77.3	61.1	69.2	76	-9.8%
874.0	**728.9**	**801.5**	**840**	**-4.8%**

The "Upper" and "Lower" columns represent the upper and lower limits for each characteristic by using equations (2) and (3). The "IA Achieved Over One Cycle" column represents the Innovativeness calculation, using equation (4), achieved by the program in the cycle. The "80% Target number" indicates the number corresponding to 80% of the maximum achievable number for the characteristics. The "% Deviation" represents the deviation from the set goal. The last row in table 5 indicates the sum for each of the first four column entries and the average deviation for the last column. Therefore, the overall innovation measure for this sample program is 801.5, and the 80% target (using the same percentage as the one in the sample assessment data) is 840. This means that the program is 4.8% off its 80% innovation target goal and needs to make proper adjustments.

Using Table 4 and Table 5 data along with equations 1-4 gives us the following data set for the entrepreneurship calculations:

TABLE 6: ENTREPRENEURSHIP CALCULATIONS

Upper	Lower	IA Achieved Over One Cycle	80% Target Number	% Deviation
58.4	45.0	51.7	56	-8.3%
4.2	3.8	4.0	4	-0.8%
20.9	16.1	18.5	20	-8.3%
12.2	11.3	11.8	12	-2.1%
64.5	55.1	59.8	60	-0.3%
68.8	58.8	63.8	64	-0.3%
83.5	64.3	73.9	80	-8.3%
25.0	20.3	22.6	24	-6.0%
17.2	15.1	16.1	16	0.8%
69.2	64.0	66.6	68	-2.1%
8.6	7.5	8.1	8	0.8%
58.4	45.0	51.7	56	-8.3%
30.1	28.5	29.3	28	4.4%
71.5	61.1	66.3	76	-14.6%
38.7	28.9	33.8	36	-6.5%
50.1	45.2	47.6	48	-0.8%
37.7	37.7	37.7	40	-6.2%
33.4	27.0	30.2	32	-6.0%
44.8	35.3	40.1	44	-9.8%
73.3	57.8	65.6	72	-9.8%
870.4	**727.6**	**799.0**	**844**	**-5.6%**

The last row in table 6 indicates the sum for each of the first four column entries and the average deviation for the last column. Therefore, for this sample program, the overall entrepreneurship measure is 799.0. and the 80% target (using the same percentage as the ABET assessment) is 844. This means that the program is 5.6% off its 80% entrepreneurship target goal and needs to make proper adjustments.

Calculations in Table 5 and Table 6 assume that the innovative characteristics have an equal effect on each outcome [27]. The different weights are considered for only the overall innovation calculation. This means, for example, the data for ABET outcome four has the same effect as outcomes one and two in calculating "alternative seeker." By modifying this assumption and assigning different weights to outcomes, we believe the IA calculations represent a more accurate representation of individual characteristics. Tables 7 and 8 show the implementation of this improvement for innovation and entrepreneurship calculations.

TABLE 7: INNOVATION CALCULATIONS USING MODIFIED WEIGHTING APPROACH

Upper	Lower	IA Achieved Over One Cycle	80% Target Number	% Deviation
76.1	54.6	65.4	68	-4.0%
68.9	56.5	62.7	60	4.3%
71.6	51.4	61.5	64	-4.0%
53.8	52.9	53.4	52	2.6%
47.3	36.7	42.0	40	4.8%
17.2	16.2	16.7	16	4.1%
83.5	64.3	73.9	80	-8.3%
75.1	66.8	71.0	72	-1.4%
47.3	44.8	46.0	44	4.4%
37.3	36.6	37.0	36	2.6%
34.4	30.1	32.3	32	0.8%
58.4	45.0	51.7	56	-8.3%
14.2	12.2	13.2	12	9.1%
3.8	3.2	3.5	4	-14.6%
25.8	19.3	22.5	24	-6.5%
53.7	45.2	49.5	48	2.9%
26.4	26.4	26.4	28	-6.2%
20.9	18.6	19.7	20	-1.4%
8.1	7.1	7.6	8	-5.2%
85.1	61.1	73.1	76	-4.0%
908.8	**748.8**	**828.8**	**840**	**-1.3%**

TABLE 8: ENTREPRENEURSHIP CALCULATIONS USING MODIFIED WEIGHTING APPROACH

Upper	Lower	IA Achieved Over One Cycle	80% Target Number	% Deviation
62.7	45.0	53.8	56	-4.0%
4.6	3.8	4.2	4	4.3%
22.4	16.1	19.2	20	-4.0%
12.4	12.2	12.3	12	2.6%
71.0	55.1	63.0	60	4.8%
68.8	64.7	66.7	64	4.1%
83.5	64.3	73.9	80	-8.3%
25.0	22.3	23.7	24	-1.4%
17.2	16.3	16.7	16	4.4%
70.4	69.2	69.8	68	2.6%
8.6	7.5	8.1	8	0.8%
58.4	45.0	51.7	56	-8.3%
33.1	28.5	30.8	28	9.1%
71.5	61.1	66.3	76	-14.6%
38.7	28.9	33.8	36	-6.5%
53.7	45.2	49.5	48	2.9%
37.7	37.7	37.7	40	-6.2%
33.4	29.7	31.5	32	-1.4%
44.8	38.9	41.8	44	-5.2%
80.6	57.8	69.2	72	-4.0%
898.4	**749.0**	**823.7**	**844**	**-2.5%**

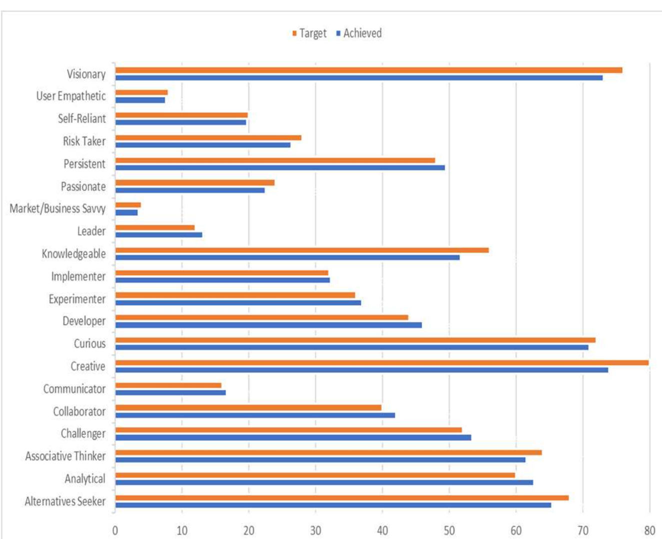

Fig. 3: Innovation Calculations Using Modified Weighting Approach

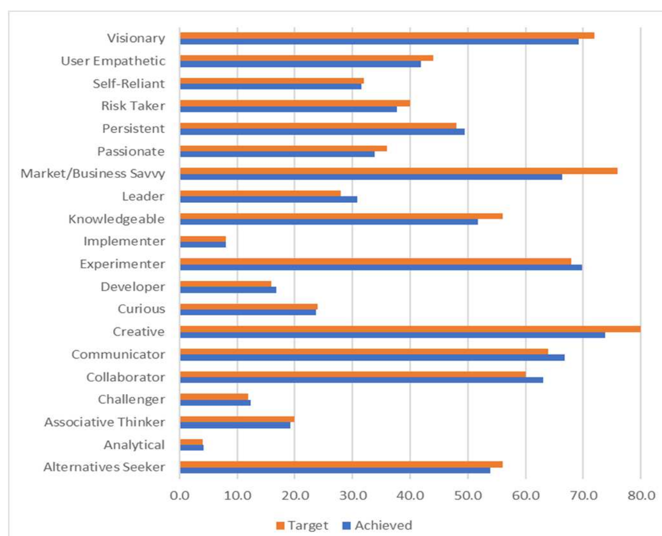

Fig. 4: Entrepreneurship Calculations Using Modified Weighting Approach

Figures 3 and 4 show the data in Tables 7 and 8 in a different format.

We define the curriculum's innovativeness measure (IM) by averaging the IAs for three consecutive cycles, assuming that ABET data collection for the seven outcomes is repeated every two years, ($IM = \left(\sum_{cycle=1}^{cycle=3}(IA)_{cycle}\right)/3$.) This approach takes continuous improvement into consideration. If we repeat the same process but use the minimum of the average numbers, we will have a range for the IM. We suggest defining a target number for the IM. Since the data comes from the ABET assessment process, we can identify the courses that can increase the IM number to meet a higher target. By focusing on the maximum (minimum) PI as the base for IA calculation, we can identify the leading (lagging) contributor(s) to the innovativeness measure and therefore provide a pathway for further curriculum enhancement.

VI. Remarks and Conclusion

In this work, we presented an approach to measure the innovativeness and entrepreneurship of an engineering curriculum by using the ABET's criterion 3 assessment process and data from criterion 4. Weighted engineering innovator characteristics were mapped to the ABET Criterion 3 and were used as the base for our calculations. We considered two different weighting for innovation and entrepreneurship calculations but kept the mapping the same as in [27] and then showed a modified version of the calculation by considering a weighted mapping for the outcomes in IA calculations. Equations to calculate IAs and IM are intentionally chosen to be linear and straightforward so that the focus be on the methodology. The innovation (entrepreneurship) calculation can be improved by considering (assigning) individual weighting factors to each PI in an outcome, rather than simple averaging method. Further improvement can be achieved by adding uncertainties to the weighting factors and using methods such as fuzzy logic.

We plan to continue this work and incorporate other research works related to the assignment of the impact factors and assessment associations in Table 1 and Table 2.

The proposed scheme also reveals the usefulness of the student outcomes assessment data beyond the ABET accreditation requirement. Given the nature of the collected data, we should point out that the proposed calculation cannot be used to compare programs unless the programs have the same PIs and it is only a self-assessment indicator.

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