Road map of power electronics knowledge and skills for enhancing engineering graduates' employability

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ROAD MAP OF POWER ELECTRONICS KNOWLEDGE AND SKILLS FOR ENHANCING ENGINEERING GRADUATES' EMPLOYABILITY

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Abstract

Undoubtedly, the power electronics industry covers a breadth of application areas and markets that many other industries can match. It is essential for the efficient conversion and conditioning of energy in a wide range of applications, for example, but not limited to smart grids and electric vehicles. Accordingly, the power electronics industry strives for more knowledgeable and skilled graduates. Hence, The electrical engineering curriculum should be supported by market-oriented knowledge and industry skills based on the industry employers' vision and recruiting plans. This paper explores the needed power electronics knowledge and skills from the perspective of industry employers. The study is based on a survey targeting 38 academics and 18 industry representatives regarding the gaps in the Power Electronics and Machine Drives (PEMD) curriculum. The survey leads to the presented road map of power electronics knowledge and skills. This road map addresses the curriculum framework and the required employability skills in the power electronics industry.

1 Introduction

Power electronics is considered a hidden industry, but it is mandatory as it contributes nearly £50bn annually to the UK economy with over 400 identifiable companies and organisations operating in the space [1] - [3]. The supply chain supports 82,000 high-value jobs in design and manufacture, of which 50,000 are at the graduate level [1], [3] - [6]. So, from the perspective of industry employers, the inability to recruit high-quality engineers in the power electronics field is considered a crucial point. To successfully have a high-quality power electronics engineer and narrow the gap between academic institutions and industry, the key adaptation mechanisms are

- Curriculum assessment based on the industry employers' feedback should be considered. Some academic institutions still deliver inappropriate or outdated teaching materials [1], [4].
- Teaching material should include the basics and relevant depth of the latest knowledge required by the power electronics industry.
- Teaching material should be imbued with the latest research in the field.
- Teaching power electronics should be upskilled to practical and training levels.
- The power electronics curriculum should include and addresses employability skills [4] – [6].

References introduced employability skills based on a specific discipline or programme [4] – [6]. This work aims to embed employability skills in the power electronics curriculum. However, the teaching effectiveness and quality of teachers are not included in this manuscript.

The employability term has different definitions or can be interpreted in several ways [4], [5], [8]-[11]. One of these definitions is "*A set of achievements – skills, understandings and personal attributes – that makes graduates more likely to gain employment and be successful in their chosen occupations, which benefits themselves, the workforce, the community and the economy*" [5]. Another short but comprehensive definition is *"Skills which lead to take a decision with incomplete data."*

Employability skills, including core knowledge and personal qualities, are introduced in many articles and references, for example, [8] – [12]. The majority of references agree that the graduate's essential employability skills can be enumerated as follows: Leadership, teamworking, independence, adaptability, resilience, creativity, initiation, critical thinking, excellent communication skills, problem-solving skills, and time management. Accordingly, employability skills are transferable, and the graduate engineer should be competent and adapted to market needs. Hence, as university teachers, we should slip the following message to our students from day one [4]. "*Employability skills are not something that can be ignored. Enhancing employability skills from an early stage will increase the chance of securing a chosen career"*.

In this paper, a survey that includes more than 22 questions is conducted between 38 academics and 18 industry employers regarding the gaps in the PEMD curriculum. We will focus on the responses which directly affect employability and employability skills. This survey leads to the production of a road map of power electronics, including the required knowledge and skills. Moreover, the power electronic-oriented framework is introduced. After the introduction, the essential skills for electrical engineering graduates are presented in section 2. The industry and academics feedback is given in section 3. The road map and power electronics framework, including the discussion and impact of this road map on employability skills for the power electronics sector, are presented in section 4.

2 Key Skills for Power Electronics Engineer

In most UK universities, the number of credit hours to power electronics modules is limited to 20 or 40 credits (10 credits represent one contact hour per week). The limited contact hours present challenges to cover all basics and the updated technology required by the power electronics industry employers. Some industry employers provide induction training, but this costs them money and time. In addition, they have less tendency to recruit a graduate with narrow knowledge about the required job needs. The key skills are divided into technical and soft skills.

The technical skills are relevant to academic qualifications, a Bachelor's or Master's degree based on the level of specialisation. In this degree, the student should cover a good level of mathematics and analysing skills. Math is critical in electrical engineering; for example, power electronics include transient analysis, troubleshooting, loss calculation, and closed-loop control, and these topics are overwhelmed by math. Fundamentals of electrical and electronic circuits, including components and devices, are crucial for the power electronics engineer—the conception and design of electronic components and systems for industry or scientific research applications is another skill that the power electronics engineer should gain. Some European institutes have adopted the CDIO system (Conceive, Develop, Implement, and Operate), where 12 universities in the UK collaborate in the CDIO initiative [13]. The CDIO initiative is an educational framework that stresses engineering fundamentals set in the context of conceiving, designing, implementing and operating real-world systems and products [14]. Soft skills include attention to detail, adaptability, teamworking, critical thinking, problem-solving, leadership, and written and verbal communication skills. Dealing with electronic components requires an exceptional focus on the technical elements of a product. This point can be covered through training on reading and using datasheets. Students should know that stakeholders might change the tasks according to demand, so adaptation and continual training are necessary to enhance their adaptation skills. Any project depends on teamwork, so one of the graduate attributes is a diverse team working and how to be close with other team members to ensure the execution of the targeted plan. Leadership is a part of teamwork and how to manage the project with time management. One of the important skills is communication skills, including both verbal and written styles. Most of the taught modules in electrical engineering cover communication skills. Soft skills should be embedded in the curriculum through labs or self-learning. Students should know that one of the essential employability skills is lifelong learning or self-learning through engagement with extra-curricular and co-curricular activities, projects and volunteering work. The measurement of technical and soft skills shows the recruiters how high the graduate is and how they suit their industry.

3 The industry and academics' feedback

Starting in the past two or three decades, teaching has changed from a teacher-centred to a student-centred approach to enhance the concept of lifelong learning [7]. In the era of the teacher-centred approach, the curriculum is managed by the module leader or the instructor. Thank you to accreditation bodies which rectify this approach, and the department or the faculty controls the curriculum contents and delivery method. Nevertheless, Some academic institutions still deliver outdated materials or only focus on technical skills and do not match what employers or stakeholders require [12]. As aforementioned, power electronics engineers should establish a solid foundation in mathematics and electric circuits. So, the question is, what else or what do industry employers need from a graduate power electronics engineer beyond the foundation level? A survey is conducted between 38 academics and 18 industry employers regarding the gaps in the PEMD curriculum to enhance employability in the power electronics sector. The same question is given to industry employers and academics but in a way suitable for each side.

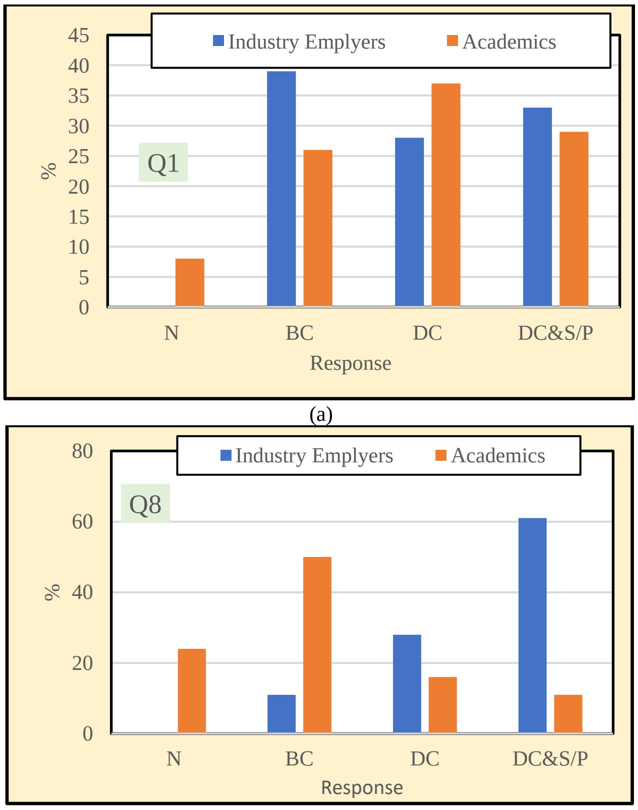
The question for industry employers is: *'If you want to recruit a power electronics engineer, select what level of knowledge the engineer should have to meet your products and business target'.* The question for academics is:

'Select the level that your curriculum addresses the following topics'. The levels are: Nothing about the topic (N), A Brief Cover (BC), A Detailed Cover (DC), or A Detailed Cover with Simulation and/or Practical work (DC&S/P). The 22 questions are illustrated in Table 1.

Table 1: Survey questions for power electronics topics

Question Number	Question
Q1	Single-phase Rectification (Controlled and Uncontrolled)
Q2	Three-phase Rectification (Controlled and Uncontrolled)
Q3	Thyristors Driving Circuits
Q4	DC/DC converters, including Buck, Boost, Buck-boost, Cuk, and flyback and forward converters
Q5	Hard and soft switching
Q6	Resonant converters
Q7	Electromagnetic interference (EMI) and printed circuit board design (PCB)
Q8	MOSFET/IGBT Gate Drivers
Q9	Silicon Carbide or GaN MOSFETs, differences between Si, SiC, and GaN from datasheets, and required driving and thermal features
Q10	Silicon Carbide Diodes, differences between Si, SiC from datasheets
Q11	Double Pulse Testing for MOSFETs and IGBT (importance, implementation)
Q12	Thermal Calculation and Heat sink design
Q13	Basics of Magnetics
Q14	High-frequency transformer design
Q15	Finite Element Modelling/Analysis for magnetic components
Q16	Sensing voltage and current circuits
Q17	Single-phase and three-phase inverters
Q18	Steady-state analysis
Q19	Small signal modelling
Q20	Closed loop control design
Q21	Software such as MATLAB/SIMULINK
Q22	Softwares such as LTspice, PCpise, PSIM, and PLECS

The results of the 22 questions are tabulated in the appendix. A sample of the results is given in fig. 1. Fig. 1a shows the response of Q1 for both industry employers and academics. There is a level of matching between both bodies. On the contrary, Fig. 1b illustrates the response of Q8, which shows a big gap between industry employers and academics. The target is to find the topics that match or mismatch the industry employers' and academics' responses. Accordingly, fig. 2 is introduced, which shows the difference between the industry employers' and the academics' responses at each level. But, fig. 2 does not indicate the gap between the industry employers and academics. In some cases, for a specific question, the response matches for one level and mismatches for the other. Therefore, it is challenging to determine the gap between the two bodies for each question or, in other words, for each power electronics topic.



(b)

Fig. 1 Industry employers and academics' responses for selected topics in power electronics topics (a) Q1 and (b) Q8

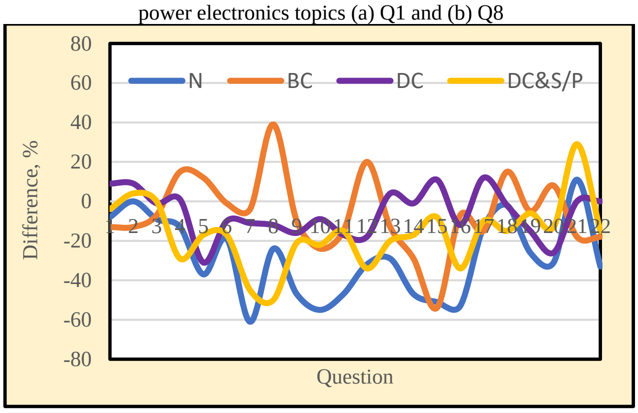


Fig. 2: Difference between the industry employers' and the academics' responses at each level

The response weight methodology is used to determine the gap between industry and academia in the power electronics discipline, where each response should have a weight. Suppose we assume that industry and academia are matching for all levels (i.e. the absolute difference in responses for each level is zero or close to zero). Hence, we consider this case highly matched and equivalent to 100%. If we distribute the 100% to 4 levels, each level has a weight of +25. In this case, three ticks can represent each level as '✓✓✓'. Each tick weight (100/(3 ticks*4 Levels) = +8.3. Suppose the industry and academia are not matching for all levels (i.e. the difference in responses for each level is maximum, above 25 %). In that case, each level can be represented by three crosses, ' xxx'. Each cross weighs -8.3. The distribution of weights is given in Table 2.

Table 2: Weight Distribution

Level	Absolute Difference (D)	Tick/ cross	Weight
High Match	$0 \le D \le 5$	✓✓✓	+25
Match	$5 < D \le 10$	✓✓	+16.7
Low Match	$10 < D \le 15$	✓	+8.3
Low mismatch	$15 < D \le 20$	x	-8.3
Mismatch	$20 < D \le 25$	xx	-16.3
High mismatch	$25 < D \le 30$	xxx	-25
Extreme mismatch	> 30	xxxx	-33.3

As a case study, Table 3 indicates numerical examples for calculating the weights of questions 1 and 8. For Q1, the absolute difference for the Nothing response (N) is 8, which is considered a Match (+16.7 check Table 2). The absolute difference in the Brief Cover response (BC) is 13 (Low Match =+8.3). The absolute difference in a Detailed Cover (DC) is 9 (Match =+16.7). The absolute difference between the Detailed Cover and Simulation/Practical (DC&S/P) response is 4 (High Match = +25). Adding the weight for each level, the total weight of Q1 is +66.4. Repeat the same concept for Q8, and the total weight is -66.4. The weight for each question is added in the appendix and illustrated in fig. 3. If the weight is > +50, it is considered a good match between industry and academia. If the weight is higher than +20 and lower than +50, there is a kind of matching between both parties. If the weight is lower than +20 and higher than -20, it is considered a mismatch, while lower than -20 is a high mismatch. Fig. 3 shows the overall response weight for each question. The weight of questions 1, 2, 3, and 18 is higher than +50, indicating a match between industry and academia—for example, Q1 deals with single-phase rectification. The response shows that 8 % of academics do not cover this topic; however, the industry response shows that they need this topic which is reflected in the Brief Cover and Detailed Cover responses. For BC, 26% of the academics deliver this topic, while 39 % of the industry wants a brief cover. Sixty-one % of the industry wants the graduate to have a detailed cover or detailed cover with a practical or simulation of single phase rectifier. On the other side, 66% of the academics deliver the topic of single-phase rectification with a detailed cover or detailed cover with practical or simulation. This topic indicates a good match between industry and academia, as proven by the weight concept. Questions 6, 17, and 19 show a relative matching between industry and academia.

But, academics should consider in their modules/courses the topics of resonant converters, single/three-phase inverters, and small-signal modelling. The remaining topics indicate a gap between industry requirements and what academics deliver in the power electronics modules. Accordingly, as presented in section IV, the authors suggested a power electronics roadmap and curriculum framework narrowing the gap between industry employers and the academic sector and identifying the required skills and knowledge for the power electronics industry.

Table 3: Example of weight calculation

	N (%)	BC (%)	DC (%)	DC&S/P (%)	Weight
Q1	8 ✓✓	13 ✓	9 ✓✓	4 ✓✓✓	+66.4
Q8	24 xx	39 xxxx	12 ✓	50 xxxx	-66.4

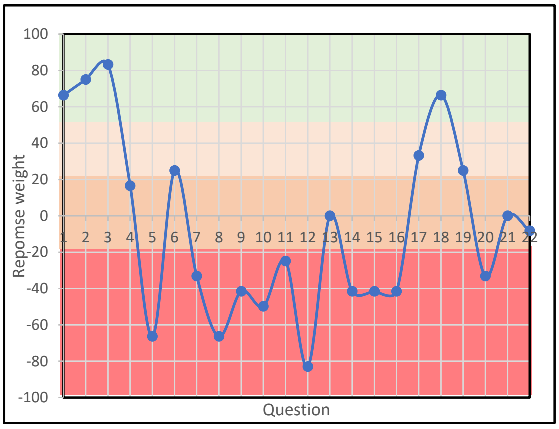


Fig. 3: Weight for questions

4 Power electronics road map and curriculum framework

Section 3 presented and analysed the feedback between industry employers and academia for power electronics topics. The study shows a clear gap between both parties where the graduates need more knowledge and skills to join the power electronics industry smoothly. Some of the identified gaps are enumerated as follows

- The majority of lecture time focuses on the online commutated rectifier circuits while, nowadays, more circuits depend on wide band gap devices.
- Some curriculums do not include simulation and practical activities
- Switch selection, components design and efficiency assessment, including advanced technologies
- Understand and pick up data from the datasheet
- The link between power electronics, mathematics, physics, and control theory

The road map introduced by the authors in fig. 4 includes two main keys: knowledge and skills. The required knowledge is power semiconductors, control theory, converter topologies, magnetics design, electromagnetic interference, thermal management, and analogue and digital control. The skills are diagnostics and practical bench skills, PCB design, simulation, and software interfacing. Based on this road map, the proposed curriculum frame is divided into three levels, as illustrated in fig. 5. Level 1 is concerned with basic knowledge about power electronic switches, including a brief about material and fabrication, using and reading the datasheet and how to extract main data from it. Design gate drive circuits and identification of switching and conduction loss. Finally, this level includes basic information about magnetic cores and high-frequency transformers. In parallel to level 1, basic calculus and control theory should be covered. Level 2, or system level, is concerned with different converter topologies. The student will know about ratings, mathematical analysis, modelling, and steady-state performance at this level. Also, a brief about the difference between hard and soft switching lies under this level. Additionally, the student should know about electromagnetic interference and the fundamentals of the PCB design. Level 3 is more advanced. It includes modelling and controlling different converter topologies, leading to electric machine drives and microgrid systems. Prototyping can start from level 2, while simulation tools should start from level 1.

The road map and curriculum frame are introduced here to enhance the knowledge and employability skills of the electrical engineering graduate within the power electronics industry. On the other side, we should consider if the power electronics modules are delivered to other disciplines, such as mechanical or aerospace engineering. The length and depth should be relevant to the aimed skills in this case. Accordingly, the road map and curriculum frame might be modified to match the level of the programme.

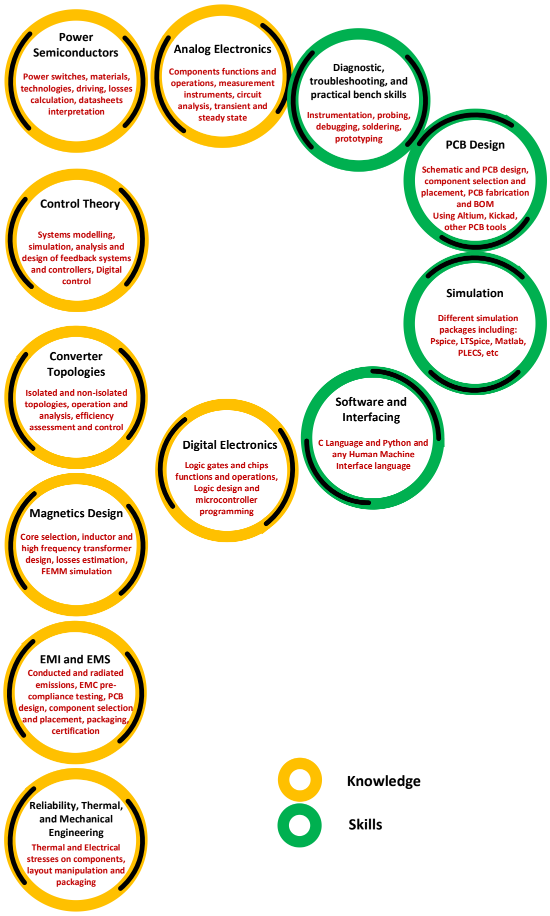


Fig. 4: Power electronics road map including knowledge and skills

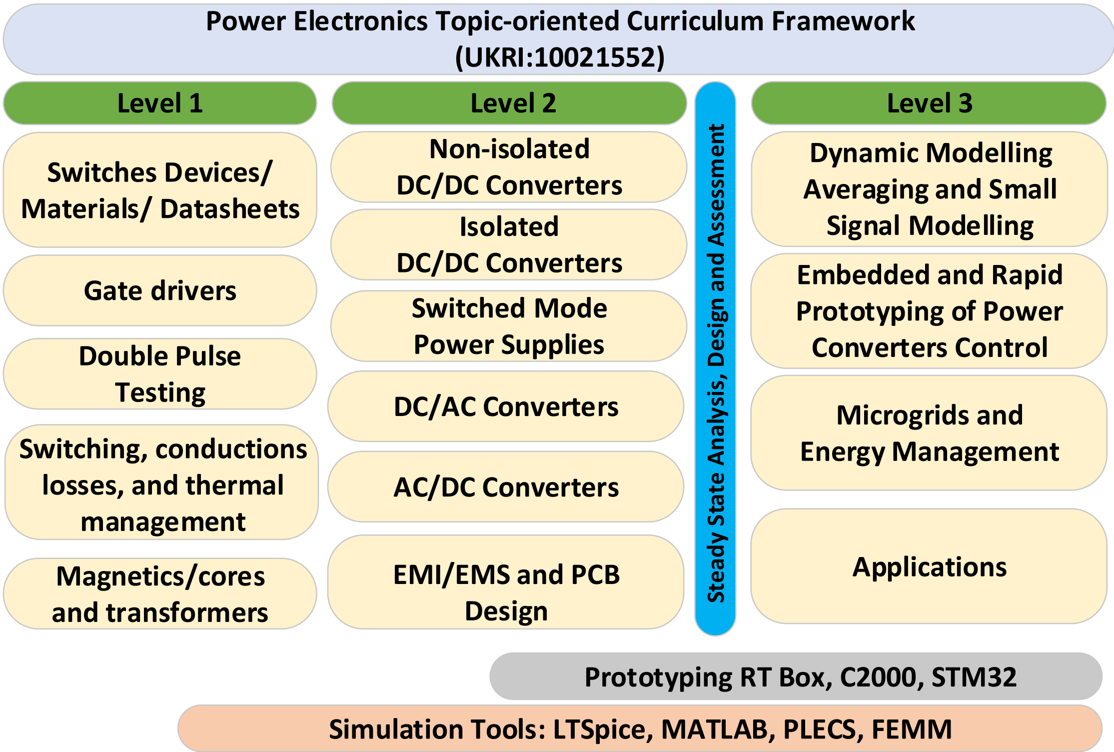


Fig. 5: Power electronics curriculum framework

5. Conclusion

In this paper, an exploration of the gap between academic institutes and industry in the Power Electronics and Machine Drives discipline has been conducted. A survey was developed and targeted academics and industry recruiters of the power electronics track. A gap has been identified in some areas where more knowledge is needed on the recent advancement of power electronics covering wide bandgap devices, DC converter design and EMI. The current curriculum also spent most of their learning and teaching time on less common topics, from the industry's perspective, where they focus on thyristors and rectification. The invested time on DC/DC converters and their efficiency assessment are minimal. Furthermore, the use of simulation software is essential. However, some academics still keep this optional, which triggers a risk in the fundamental understanding and practice. Based on the discussed results, the paper also proposed a road map to highlight the required knowledge and skills to be a power electronics engineer. A curriculum framework has also been developed to match the needs and bridge the identified gaps. This framework will bring more awareness to core knowledge and help academic educators to bring more changes to their current curriculum to drive more skilled graduates for higher employability rates.

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Appendix

	Industry employers' response			
Question	N (%)	BC (%)	DC (%)	DC&S/P (%)
Q1	0	39	28	33
Q2	11	39	28	22
Q3	33	39	17	11
Q4	0	14	33	53
Q5	0	28	44	28
Q6	11	33	28	28
Q7	0	28	22	50
Q8	0	11	28	61
Q9	0	39	22	39
Q10	0	50	17	33
Q11	22	28	22	28
Q12	0	22	28	50
Q13	0	50	17	33
Q14	11	50	11	28
Q15	17	72	0	11
Q16	0	33	22	45
Q17	11	44	17	28
Q18	6	22	39	33
Q19	11	39	28	22
Q20	10	24	33	33
Q21	22	44	0	34
Q22	32	34	0	34

	Academics' response			
Question	N (%)	BC (%)	DC (%)	DC&S/P (%)
Q1	8	26	37	29
Q2	11	26	37	26
Q3	42	32	16	11
Q4	13	29	34	24
Q5	37	40	13	11
Q6	30	32	18	11
Q7	61	24	11	5
Q8	24	50	16	11
Q9	47	29	6	18
Q10	55	26	8	11
Q11	69	13	5	13
Q12	32	42	10	16
Q13	29	37	21	13
Q14	58	21	10	11
Q15	68	18	11	3
Q16	53	26	10	11
Q17	24	29	29	18
Q18	8	37	37	18
Q19	37	34	13	16
Q20	41	32	7	20
Q21	11	26	0	63
Q22	65	16	0	19

Weight for the questions

Question	N	BC	DC	DC&S/P	Weight
Q1	✓✓	✓	✓✓	✓✓✓	+66.4
Q2	✓✓✓	✓	✓✓	✓✓✓	+75
Q3	✓✓	✓✓	✓✓✓	✓✓✓	+83.3
Q4	✓	✓	✓✓✓	xxxx	+16.6
Q5	xxxx	✓	xxxx	x	-66.4
Q6	x	✓✓✓	✓✓	x	24.9
Q7	xxxx	✓✓✓	✓	xxxx	-33.2
Q8	xx	xxxx	✓	xxxx	-66.4
Q9	xxxx	✓✓	x	xx	-41.5
Q10	xxxx	x x	✓✓	xx	-49.8
Q11	xxxx	✓	x	✓	-24.9
Q12	xxxx	x	x	xxxx	-83
Q13	xxx	✓	✓✓✓	x	0
Q14	xxxx	xxx	✓✓✓	X	-41.5
Q15	xxxx	xxxx	✓	x	-41.5
Q16	xxxx	✓✓	✓	xxxx	-41.5
Q17	✓	✓	✓	✓	+33.2
Q18	✓✓✓	✓	✓✓✓	✓	+66.4
Q19	xxx	✓✓✓	✓	✓✓	+24.9
Q20	xxxx	✓✓	xxx	✓	-33.2
Q21	✓	x	✓✓✓	xxx	0
Q22	xxxx	x	✓✓✓	✓	-8.3