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Students' Attitudes Toward Interdisciplinary Learning: A High-School Course on Solar Cells*

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Due to the lingering lack of engineers in the Western world, universities are trying to attract candidates for undergraduate engineering programs through a variety of educational activities. One of the topics at the center of this effort is renewable energy in general and solar energy in particular. Recently, a unique 20-hour interdisciplinary course on solar cells was developed. This course, combining sustainability, physics and electronics, was designed to expose twelfth-grade students with appropriate backgrounds to advanced technological applications of theoretical physics in the context of renewable energy and to arouse interest in them. The aim of the research described here was to characterize students' attitudes toward interdisciplinary learning that combines science and engineering in general and toward the course in particular. The study, which used quantitative and qualitative tools, involved 27 Israeli twelfth-grade students majoring in physics. The findings indicate that the course graduates hold positive attitudes toward interdisciplinary learning, both cognitively and affectively, and that the correlation between the attitude components is positive, moderate and significant. The students believe that the integration of science and engineering is natural, as it reflects reality. In addition, they argue that the combination is interesting and improves the understanding of the disciplinary content. As for the course itself, students claim that it is important, arouses interest, and enriches knowledge, but is also characterized by a high cognitive load.

Keywords: interdisciplinary education; students' attitudes; renewable energy; solar cells

1. Introduction

Due to the on-going shortage of engineers in the Western world, including Israel, universities and associations are trying to attract applicants for undergraduate engineering programs [1–3]. This effort covers, among other things, the development of high-school curricula in science and engineering in general [4, 5] and in nanotechnology in particular [6, 7]. Other activities focus on exposure days [8], teacher courses [9] and unique projects [10, 11].

One of the topics at the forefront of this educational initiative is energy. Safe, clean and continuous energy supply is, without a doubt, a major engineering challenge of the 21st century [12]. Therefore, high-school students are expected to be aware of renewable energy sources and devices[1] [14]. Several studies have been conducted to assess students' knowledge and attitudes toward renewable energy [15–17]. The findings reveal a lack of sufficient awareness of the sources and applications of this type of energy [18, 19].

One of the important sources of renewable energy is the Sun. Actually, the solar energy resource dwarfs all other renewable energy resources and fossil fuels combined. To be a significant source of energy, solar energy must be efficiently captured and converted by solar cells [20]. Due to the relevance of the subject, activities are held to provide high-school students with an opportunity to get acquainted and work with solar cells. Notable educational initiatives include solar cell characterization in the laboratory [14, 21] and the design of solar-powered model cars [22]. In addition, students build solar cells that turn light bulbs on [23] and visit renewable energy centers, focusing on solar chimneys [24].

In light of the social impact of renewable energy in general and solar energy in particular [20], and in view of the need to provide students with relevant knowledge at relatively early stages [17, 25], a 20-hour interdisciplinary course on solar cells has recently been developed at the Technion – Israel Institute of Technology. This course, combining sustainability, physics and electronics, was designed to expose twelfth-grade students with appropriate backgrounds to advanced technological applications of theoretical physics in the context of renewable energy and to arouse interest in them. The course discusses in depth the structure and principle of operation of solar cells and covers relatively complex topics, e.g., electromagnetic waves, black-body radiation, atomic physics, light-matter interaction, and semiconductor physics and devices. Thus, it is fundamentally different from the educational activities on solar cells described above.

The research described in the paper character-

[1] Renewable energy is energy that is created in natural, continuous and non-perishable processes, e.g., wind energy and solar energy [13].

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ized, using quantitative and qualitative tools, the attitudes of the course graduates toward interdisciplinary learning that combines science and engineering in general and toward the course in particular. To the best of the authors' knowledge, such characterization was performed here for the first time. The findings of the study may expand the body of knowledge on the subject and promote the development of interdisciplinary curricula in science and engineering. The authors believe that these contributions are further validated in light of the interpenetration of science and engineering in the current digital epoch [26, 27]. This blurring of boundaries sharpens the importance of interdisciplinary programs, providing the student with a toolbox relevant for the times we live in [28].

The paper opens with a theoretical background that reviews relevant aspects of interdisciplinary education. Next, the course "Solar Cells" is described. Then, the research goal and methodology are presented. Finally, the main findings are discussed.

2. Interdisciplinary Education

Interdisciplinarity refers to activities that unite or combine two or more fields of knowledge. The integration between disciplines is designed to create a meaning, explanation, or product that is more powerful than the sum of its components [29]. If two or more areas of knowledge are represented but integration does not exist, then the appropriate term is multidisciplinarity [30]. The case of the opposite extreme, in which the synthesis is particularly extensive to the point of blurring the boundaries between the original disciplines, is referred to as transdisciplinarity [31] (Fig. 1).

Between multidisciplinarity and interdisciplinarity, two intermediate levels can be defined [32]. The first level closer to multidisciplinarity is pluridisciplinarity, i.e., grouping two or more disciplines in order to strengthen the connection between them. An example of this is a faculty at a university, which consists of departments. The second intermediate level closer to interdisciplinarity is crossdisciplinarity, namely, a one-way use of tools and concepts of a given field of knowledge in another discipline. A clear example is the use of mathematical tools to describe physical phenomena.

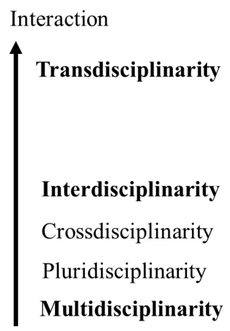

Fig. 1. Degrees of interaction between disciplines.

There are additional classifications for the degree of interaction between disciplines. Thus, for instance, a four-level scale has been proposed, ranging from informed-disciplinarity with an emphasis on a single discipline where other disciplines are used to shed light on specific issues of the discipline discussed, to conceptual interdisciplinarity, in which several disciplinary perspectives are combined, without a solid disciplinary basis [33]. In another notable four-level hierarchy, the minimum level of interaction is manifested in unidisciplinarity, where the focus is on a single discipline. The maximum degree of interaction is extended interdisciplinarity, focusing on the ability to transfer interdisciplinary knowledge to new topics [34].

The integration of disciplines often promotes cognitive skills at different levels, from the lower levels of knowledge and comprehension [35] to the higher levels of analysis, synthesis and evaluation [33, 36]. According to the literature, students remember and understand better when they study interdisciplinary topics [37]. Moreover, critical thinking and systems thinking [28, 38, 39] can be developed in interdisciplinary courses using diverse perspectives that go beyond the disciplinary one [33]. Thus, interdisciplinary curricula may assist students cope with the complex work environments that characterize modern society [34].

With the help of Piaget's theory of cognitive development [40], the advantage of interdisciplinary learning over disciplinary learning can be explained as follows. Compared to disciplinary curricula, interdisciplinary syllabi provide more opportunities in which the learner can link new knowledge with knowledge he/she has acquired in the past. Therefore, learning is more effective in the latter case. Beyond the cognitive aspect, discussed above, interdisciplinary learning also has a benefit in the affective domain. This advantage is the enhancement of intrinsic motivation to learn due to the interest interdisciplinarity creates [33, 41, 42].

Following the benefits inherent in interdisciplinary education, interdisciplinary programs have been developed on various topics, such as nanotechnology, biotechnology and aerospace, for students in academia [43], high schools [44] and junior-high schools [45]. Studies conducted in these and other courses indicated challenges involved in interdisciplinary teaching and learning. Prominent challenges are associated with the difficulty of faculty to teach a field or fields of knowledge that they have not been trained to teach and finding the proper

Table 1. Key conditions needed for the success of interdisciplinary programs

Factor	Conditions
Teacher	• Has relevant education and experience • Involved in program development • Team player
Content	Proper balance between the disciplinary components and the interdisciplinary ones
Student	• Curious • Open minded • Patient
Environment	Financial and organizational support from management

balance between the disciplinary and the interdisciplinary contents [46, 47]. Thus, success is not guaranteed, and some of the programs are actually multidisciplinary or pluridisciplinary rather than interdisciplinary [48]. The key conditions needed for the success of interdisciplinary programs relate to the four factors involved in the learning process, namely, teacher, content, student and environment [48], as detailed in Table 1.

3. The Course "Solar Cells"

The interdisciplinary course "Solar Cells" was developed for twelfth-grade students majoring in physics. The Israeli high-school curriculum in physics focuses on classical mechanics, electromagnetism and modern physics, and is based on theory classes and laboratory sessions.

The course is comprised of six theory sessions and a virtual visit to a laboratory for the fabrication and characterization of solar cells (The Photovoltaics Laboratory, Micro-Nano Fabrication and Printing Unit, Technion – Israel Institute of Technology).

At the end of the course the student should be able to:

- Explain the need for renewable energy and name prominent renewable energy sources;
- Explain basic concepts in wave theory;
- Describe the electromagnetic spectrum and relevant technological applications;
- Explain what black-body radiation is and describe its properties;
- Describe key models of the atom and explain how photon emission and absorption processes take place;
- Define what a semiconductor is and explain the difference between it and a conductor and an insulator;
- Analyze the structure and principle of operation of a diode;
- Describe how a solar cell is fabricated and analyze its structure and principle of operation.

According to Bloom's taxonomy (cognitive domain) [49], the learning goals apply to both lower- (comprehension) and higher- (analysis) order thinking. The inclusion of the latter stems from their necessity for studying science and engineering [50, 51] and because they characterize, as explained in Section 2, interdisciplinary education [33, 36].

First, the course introduces the need for renewable energy and discusses relevant energy sources, e.g., geothermal, hydroelectric, wind and solar energy (1 hour). Next, the course reviews basic concepts in wave theory, i.e., longitudinal and transverse waves, amplitude, wavelength, period, frequency and velocity (1 hour). The course then deals with electromagnetic waves and reviews the electromagnetic spectrum, ranging from gamma rays to radio waves, explaining physical properties and relevant technological applications, such as radiotherapy, night-vision devices, microwave ovens and TV broadcasting (1 hour). The next chapter covers black-body radiation, namely, Planck's law, Wien's displacement law and Stefan-Boltzmann law, and models the Sun as an approximate black body (2 hours). Then, the course reviews, in chronological order, the main models proposed for the atom, i.e., Dalton model, Thomson model, Rutherford model and Bohr model, emphasizing their strengths and limitations. Absorption of light and spontaneous emission are also discussed in this section (3 hours). Next, the course deals with semiconductors (3 hours), starting with the difference between conductors, semiconductors and insulators, both macroscopically (conductivity) and microscopically (band diagram). Subsequently, the course covers intrinsic and extrinsic semiconductors (N- and P-types) and generation and recombination. The next chapter deals with diodes and analyzes relevant processes (drift and diffusion) as well as the voltage-current characteristic (forward and reverse bias) (2 hours). The last part of the course focuses on the fabrication, structure and principle of operation of solar cells, including quantum efficiency and current-voltage curves (7 hours). The course is based, inter alia, on the textbooks Principles of Electronic Materials and Devices [52] and Semiconductors and Electronic Devices [53]. Table 2 displays the course syllabus.

Instruction is based on presentations that include text and pictures, accompanied by explanations from the course faculty. In addition, relevant videos are shown. Students are given two assignments. The first task deals with black-body radiation (calculating the peak wavelength of stars). The second exercise focuses on atomic physics and light-matter interaction (using the Bohr model to calculate the absorption spectrum of the hydrogen

Table 2. The course "Solar Cells" – syllabus

Topic	Time (hours)
Renewable energy	1
Waves (review)	1
Electromagnetic spectrum	1
Black-body radiation	2
Atomic physics and light-matter interaction	3
Semiconductors	3
Diodes	2
Solar cells	7
	20

atom). As mentioned, as part of the last chapter (solar cells), a virtual visit takes place at the Photovoltaics Laboratory at the Technion – Israel Institute of Technology. As part of the visit, laboratory simulations (current-voltage curves of a solar cell) are presented and a tour is conducted in clean rooms, where solar cells are fabricated, and on the roof of the building on which various types of solar panels are installed. The assessment is based on the two assignments mentioned above and a report summarizing the visit.

An attempt was made to provide an appropriate response to the main challenges involved in developing and teaching interdisciplinary curricula discussed in Section 2. Thus, for example, emphasis was placed on a proper balance between the course disciplinary components and the interdisciplinary ones. In addition, given the importance attached to the education and experience of faculty teaching interdisciplinary courses and their involvement in the development process, members of the course development and teaching staff held advanced degrees in science and engineering and had rich teaching experience. Finally, the course was supported by school management.

4. Goal

The aim of the study was to characterize the attitudes of the solar cells course graduates toward interdisciplinary learning that combines science and engineering in general and toward the course in particular.

The following questions were formulated:

- What are students' attitudes toward the course?
- What are students' attitudes toward interdisciplinary learning that combines science and engineering?

5. Methodology

5.1 Participants

The study involved 27 Israeli twelfth-grade students majoring in physics. These students attended the "Solar Cells" course, and their parents gave their consent to take part in the study. The students have not previously been exposed to interdisciplinary learning. The participants were similar in their characteristics to Israeli high-school students majoring in physics.

5.2 Method

The study used quantitative and qualitative tools in order to increase the findings' trustworthiness and to enable the presentation of various aspects of the phenomenon under study [54].

At the end of the course, students filled out a closed-ended anonymous questionnaire, designed to characterize their attitudes (cognitive and affective components) toward interdisciplinary learning that combines science (physics) and engineering (electronics). In addition, at the end of the course, the students completed an open-ended anonymous questionnaire and seven of them were interviewed. The open-ended questionnaires and the semi-structured interviews were intended to characterize students' attitudes toward interdisciplinary learning in general and toward the course in particular.

The quantitative data were statistically analyzed. First, Kolmogorov-Smirnov test for normality was conducted to check whether a normal distribution of the attitude component scores could be assumed. Next, based on the test results, the appropriate correlation coefficient between the attitude components was calculated. The interviews were recorded and transcribed in full. The qualitative data (open-ended questionnaires and interviews) were classified into categories based on a directed content analysis [55] performed by two engineering education experts. The analysis relied on Rosenberg and Hovland's tri-component attitude model (ABC model) [56]. Only information that has risen at least three times was included in this analysis.

5.3 Instruments

The self-reporting questionnaire used for evaluating students' attitudes toward interdisciplinary learning was a five-level Likert-like scale, ranging from "strongly disagree" (1) to "strongly agree" (5). The questionnaire was based on a scale developed by Fishbein [57]. The questionnaire included 15 statements expressing cognitive and affective aspects toward interdisciplinary learning that combines science (physics) and engineering (electronics). About half of the statements reflected positive attitudes and the rest – negative ones. The statements were validated by two experts in engineering education. Cronbach's alpha of the cognitive component (α = 0.80) and that of the

Table 3. Closed-ended questionnaire – sample statements

Component	Polarity	Statement
Cognitive	Positive	Technological development depends on scientific progress (and vice versa), therefore science should be studied in combination with engineering
	Negative	The combination of physics and electronics is difficult because the student has to deal with several topics at once
Affective	Positive	The interdependence between physics and electronics is interesting
	Negative	The combination of physics and electronics is boring because it repeats the same topics several times

affective component (α = 0.75) indicated acceptable internal consistency. Sample statements are given in Table 3.

A sample of the open-ended questions is provided in Appendix A, and a sample of the interview questions is given in Appendix B.

6. Findings

The main findings of the study are given below. First, findings on the attitudes of the course graduates toward the course itself are introduced. Then, those on interdisciplinary learning are presented.

6.1 Attitudes Toward the Course

Content analysis revealed cognitive, affective and behavioral components in students' attitudes toward the course.

6.1.1 Cognitive Domain

Students identified both benefits and challenges inherent in the course. As for the benefits, a majority of the respondents (67%) indicated the exposure to technological applications based on theoretical physics as one of the most successful features of the course:

> "[The best thing about the course is] the examples of real-world uses of physics." (questionnaire)

About half of the respondents (46%) believed that the course enriched students' knowledge:

> "It [the course] gave me an understanding of how solar cells work... These are things we usually learn less, so it was very successful. . . it expanded our horizons." (interview)

About a third of the respondents (34%) indicated the importance of the course topic:

> "I think the subject [of the course] is the best thing... It's a very important subject. . . I think everyone should be aware of the importance of renewable energy." (interview)

A quarter of the respondents (25%) mentioned the high quality of the faculty, both in terms of its proficiency:

> "[The best thing about the course was] the extensive knowledge of the lecturers. Almost every question had an answer." (questionnaire)

and in terms of the treatment of students:

> "[The best thing about the course is] the way they [course faculty] treats students." (questionnaire)

Thirteen percent of the respondents found exposure to content usually taught at the university as one of the advantages of the course:

> "I was happy to find out that we studied advanced topics in modern physics usually taught at the university." (interview)

Along with the benefits outlined above, students also identified challenges inherent in the course. Half of the respondents (50%) reported a high cognitive load:

> "It was a bit difficult, mainly because there were a lot of new concepts that we were not familiar with." (interview)

and 38% of them referred to a too fast teaching pace:

> "I think in some subjects this course may have progressed a little too fast." (interview)

6.1.2 Affective Domain

Most respondents (79%) found the course interesting:

> "The course was really, really interesting." (interview)

and some (38%) found it enjoyable:

> "It was really fun and entertaining." (questionnaire)

6.1.3 Behavioral Domain

A vast majority of the respondents (88%) would recommend their friends (interested in science and engineering) to participate in the course or similar:

> "Obviously, I would recommend it [the course] to all students studying physics or electrical engineering." (interview)

Tables 4–5 summarize students' attitudes toward the course.

6.2 Attitudes Toward Interdisciplinary Learning

Table 6 shows the mean score ($1 \leq M \leq 5$) and standard deviation (*SD*) of the attitude (and its components) of the course graduates toward interdisciplinary learning that combines science (physics) and engineering (electronics). It seems that the

Table 4. Students' attitudes towards the course (cognitive domain)

Category	Subcategory	Frequency (%)	Example	Interpretation
Strengths	Exposure to technological applications	67	[The best thing about the course was] to see how theoretical things happen in the field. (questionnaire)	The course presents technological applications of theoretical physics
	Expanding horizons	46	It [the course] enriches knowledge. (questionnaire)	The course enriches students' knowledge
	Importance of the subject	34	[The best thing about the course was] the importance of the topic, namely, solar cells. (questionnaire)	The course deals with an important topic
	Teaching staff	25	The best thing about the course was the teaching staff who taught the material in the best way. (questionnaire)	The faculty is excellent
	Exposure to content taught in academia	13	It [the course] gave me some idea of what one studies at the university. (questionnaire)	The course exposes students to content taught at the university
Challenges	High cognitive load	50	[The worst thing about the course was] the information overload. (questionnaire)	The cognitive load is high
	Fast teaching pace	38	I think the pace, it was too fast... at some point I had a hard time understanding the subject. (interview)	The teaching pace is too fast

Table 5. Students' attitudes towards the course (affective and behavioral domains)

Component	Category	Frequency (%)	Example	Interpretation
Affective	Creating interest	79	The course was very interesting. (questionnaire)	The course creates interest
	Creating pleasure	38	It was really fun. (questionnaire)	The course creates pleasure
Behavioral	Recommending the course	88	If it [science or engineering] interests them [my friends], then yes [I would recommend them to attend the course]. (interview)	Students would recommend their friends to attend the course

Table 6. Attitude component scores (mean and standard deviation)

Component	*M*	*SD*
Cognitive	3.67	0.47
Affective	3.90	0.79
In total	3.72	0.48

course graduates hold a positive attitude toward interdisciplinary learning. This positive attitude is expressed both cognitively and affectively.

According to Kolmogorov-Smirnov test for normality, a normal distribution can be assumed for the scores of the cognitive component ($D = 0.08$, $p > 0.05$) and that of the affective component ($D = 0.21$, $p > 0.05$). Pearson correlation coefficient between the two attitude components is positive, moderate, and significant ($r = 0.51$, $p < 0.01$).

Content analysis indicated cognitive and affective aspects in students' attitudes toward interdisciplinary learning. From the cognitive perspective, one-fifth of the respondents (20%) believe that the integration between physics and electronics reveals the applied aspect of physics:

> "It [the combination of physics and electronics] is important and right. It presents a different and practical side of theoretical physics." (questionnaire)

and improves the understanding of the disciplinary content:

> "I think this [the combination of theory and practice] is very successful and contributes to the understanding [of physics and electronics]." (interview)

Moreover, one-fifth of the respondents (20%) claim that the connection between physics and electronics is natural:

> "You can't separate engineering, especially electrical engineering, from physics. . . you can't study engineering without its basis, and you can't study physics without its technological applications." (interview)

Finally, according to 16% of the respondents, the integration makes it possible to look at the subject from several perspectives:

> "When there is integration, you can see many aspects." (interview)

Affectively, 44% of the respondents indicate that

Table 7. Students' attitudes toward interdisciplinary learning

Component	Category	Frequency (%)	Example	Interpretation
Cognitive	Exposure to the applied aspect of physics	20	I think the combination [of physics and electronics] is right because it shows us how theory is related to practice. (questionnaire)	The combination of physics and electronics reveals the applied aspect of physics
	Improving understanding	20	I think it is a good idea to combine these two disciplines [physics and electronics] because that way they can be better understood. (questionnaire)	The combination of physics and electronics improves the understanding of the disciplines themselves
	Natural connection	20	I definitely prefer to combine the disciplines [physics and electronics] because that way it shows us what we have in real life... because in real life, physics blends in with other things. (interview)	The combination of physics and electronics reflects reality
	Observing from several viewpoints	16	I think the combination of physics and electronics provides other ways of looking at things. (questionnaire)	The combination of physics and electronics makes it possible to look at a subject from several perspectives
Affective	Creating interest	44	A wonderful combination [of physics and electronics] that I would like to experience more because it is interesting. (questionnaire)	The combination of physics and electronics is interesting

the integration between electronics and physics is interesting:

> "It [the combination of physics and electronics] is interesting." (questionnaire)

Table 7 summarizes students' attitudes toward interdisciplinary learning that combines science and engineering.

7. Discussion

The paper presented an interdisciplinary course on solar cells designed to expose high-school students to advanced technological applications of theoretical physics in the context of renewable energy and to arouse interest among them.

The first research question focused on students' attitudes toward the course. The study revealed cognitive, affective and behavioral components in their attitudes. In the cognitive aspect, students identified benefits alongside challenges inherent in the course. First, students believed that the subject of the course, namely, a particular type of renewable energy, was important. In addition, they claimed that the course expanded their horizons and even exposed them to advanced topics usually taught at the university. It is interesting to note that the latter argument, focusing on enriching knowledge at the academic level, was also found in the attitude of college students who participated in an interdisciplinary course on medical ultrasound systems [28] and in that of high-school students who attended an interdisciplinary program in electro-optics [39]. Additionally, the course graduates praised the quality of the faculty. This is particularly important because it indicates a successful response to one of the major challenges involved in interdisciplinary education, i.e., the cognitive and emotional difficulty of faculty to teach an area or areas of knowledge that they have not been trained to teach [48, 58]. In general, the benefits mentioned in students' attitudes are congruent with the findings of studies that investigated curricula combining science and engineering [41, 43].

Along with the advantages outlined above, students identified challenges inherent in the course, namely, a high cognitive load and a too fast teaching pace. The latter are recognized in the literature as characteristics of interdisciplinary education [39, 59]. They often result from the need to cover, in a limited time, a relatively large number of concepts essential to understanding the relevant disciplines.

From the affective viewpoint, students found interest and enjoyment in the course. This finding is consistent with the behavioral aspect of the attitude, according to which the vast majority of course graduates would recommend their peers (interested in science and engineering) to attend the course. It is important to note that students often find interest in courses that include "real-life" examples from their field of knowledge [60, 61], such as the current course dealing with solar cells. Thus, for instance, there was an improvement in intrinsic motivation of students who took a basic course in electrical engineering that incorporated "real-world" scenarios [62]. The explanation, according to self-determination theory, is that the need for relatedness may be satisfied due to the use of examples from students' field of knowledge and future field of practice [63, 64].

The second research question focused on the attitudes of course graduates toward interdisciplinary learning that combines science and engineering. According to the findings, students hold positive attitudes toward interdisciplinary learning, both cognitively and affectively. Moreover, the correlation between the attitude components is positive, moderate and significant. Therefore, students' interest in interdisciplinary learning can be further increased by improving their rational position on this issue (and vice versa). It is worth noting that although sometimes the components are consistent [18, 65], this is not always the case [66]. It is shown below that the qualitative findings support students' positive attitudes.

In the cognitive domain, the course graduates argue that the combination of physics and electronics improves the understanding of the disciplinary content. This finding is in line with the results of studies [35], conducted, inter alia, among pre-service teachers [47] and two-year college students [28]. Theoretically, as explained in Section 2, interdisciplinary learning provides more opportunities for the student to link new knowledge with knowledge he/she has already acquired, thus making learning more effective [40].

Course graduates believe that the combination of physics and electronics is natural, as it reflects reality. This argument, also raised by high-school students who participated in an interdisciplinary program in avionics [42], is congruent with the interpenetration of science and engineering in the current digital age [27]. The students also note that the integration between physics and electronics allows the learner to look at the subject from several perspectives. This claim expresses a major advantage of interdisciplinary curricula, namely, observing a given problem from a number of viewpoints [33]. This ability, which is one of the salient features of systems thinking [67, 68], may help students function better in the complex work environments that characterize modern society [34].

From the affective perspective, students find interest in interdisciplinary learning that combines science and engineering. This finding is in line with their attitudes discussed in answer to the first research question.

The study had one main limitation: the number of participants was relatively small. This limitation was due to the low number of students who could attend the solar cell course. In order to overcome this limitation and to increase the findings' trustworthiness, quantitative instruments were used alongside qualitative ones [54].

The main theoretical contribution of the study lies in characterizing the attitudes of graduates of an interdisciplinary course on solar cells toward interdisciplinary learning that combines science and engineering. To the best of the authors' knowledge, such characterization was carried out here for the first time. The practical contribution of the research may be reflected in the implementation of its findings for the purpose of improving and developing interdisciplinary curricula in science and engineering. In this context, the authors recommend reducing the number of concepts taught in an interdisciplinary course and allocating sufficient time to it. It is also advisable to schedule the course when the study load is not high and assign highly-qualified faculty. The authors believe that these contributions are further validated in view of the interpenetration of science and engineering in the current digital epoch [27]. This blurring of boundaries sharpens the importance of interdisciplinary programs, providing the student with a toolbox relevant to the times in which we live [28, 34].

8. Conclusions

The research described in the paper focused on an interdisciplinary course on solar cells developed for twelfth-grade students majoring in physics. According to the findings, the course graduates hold positive attitudes toward interdisciplinary learning that combines science and engineering, both cognitively and affectively, and the correlation between the attitude components is positive, moderate and significant. As for the course itself, students argue that it is important, sparks interest, and expands horizons, but at the same time characterized by a high cognitive load.

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Appendix A – Open-Ended Questionnaire

The following is a sample of the open-ended questions mentioned in Section 5.3:

- What do you think about the course?
- What do you think is the best thing about the course? Explain your answer.
- What do you think is the worst thing about the course? Explain your answer.
- Would you recommend your friends to attend the course? Explain your answer.
- What do you think about the combination of physics and electronics? Explain your answer.

Appendix B – Interview

The following is a sample of the interview questions mentioned in Section 5.3:

- What do you think about the course?
- Describe the most interesting lesson in the course. What was interesting about it? What did you learn?
- Was the course's level of difficulty suitable for you? Explain your answer.
- Would you change anything in the course? Explain your answer.
- What do you think about the combination of physics and electronics? Explain your answer.

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