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Interdisciplinary Program on Aviation Weapon Systems as a Means of Improving High School Students' Attitudes towards Physics and Engineering*

AHARON GERO
Department of Education in Technology and Science, Technion—Israel Institute of Technology, Haifa 32000, Israel.
E-mail: gero@technion.ac.il

A unique interdisciplinary program entitled 'Introduction to aviation weapon systems' was developed and implemented at a leading Israeli high school that is affiliated with the Israeli Air Force. The program integrated physics and engineering and dealt with the structure and principle of operation of weapon systems used in aviation. Twenty 12th grade students majoring in mathematics and physics participated in the program, whose objective was to enhance the students' interest in physics and engineering, demonstrate the use of these disciplines in aviation, and to stimulate their desire to continue with more advanced studies in these subjects. The research presented here used qualitative tools to characterize students' attitudes towards the program, as well as changes in their attitudes towards physics and engineering as a result of their participation in the program. Research results reveal that, in addition to the great interest the students exhibited towards the program, they believed that interdisciplinary learning that combines physics and engineering leads to a better understanding of physics. The research also shows that, following the program, the students' interest in physics and engineering increased, as did their desire to continue with more advanced studies in the subject.

Keywords: aviation; interdisciplinary education; high school students' attitudes towards physics and engineering; physics education

1. Introduction

Many high school curricula integrate engineering principles into their mathematics and science studies [1–2]. Some programs focus on nanotechnology [3–4], others on chemical engineering [5–6], information technology [7], and robotics [8–9]. The objective of such curricula is to enhance the students' interest and encourage them to develop careers in these areas, especially in light of shortages of engineering professionals [10–11], which stem, among other things, from a lack of students' exposure to engineering during their high school years [9]. Research shows that students studying in such programs exhibit improved academic performance [12–14] and improved attitudes towards science and engineering [15–16].

A unique interdisciplinary program entitled 'Introduction to aviation weapon systems' was developed and implemented at a leading Israeli high school that is affiliated with the Israeli Air Force. The program integrated physics and engineering, emphasizing the strong affinity between the two disciplines and focusing on the structure and principle of operation of weapon systems used in aviation, such as laser-based systems and thermal systems. Twenty 12th graders majoring in mathematics and physics participated in the program, the goal of which was to increase the students' interest in physics and engineering, demonstrate the use of these disciplines in aviation, and stimulate their desire to continue with higher studies in these fields.

Programs aimed at enhancing the interest of high school students in engineering are also offered by leading American military academies, such as the US Military Academy at West Point and the US Coast Guard Academy. These programs include activities such as bridge building competitions [17] and cardboard boat races [18]. The uniqueness of the Israeli program presented here is in its focus on a strictly military topic, namely modern weapon systems that are currently in use.

The research described here characterized students' attitudes towards the program, as well as changes in their attitudes towards physics and engineering. We begin the paper with a theoretical background that covers the topic of interdisciplinary education. Following the theoretical chapter, we will describe the program 'Introduction to aviation weapon systems,' and then present the research objectives and chosen methodology. After presenting our findings, we will discuss the results of the research, as well as directions for future research.

2. Interdisciplinary education

Interdisciplinarity is integration or synthesis of knowledge from different disciplines [19]. The research literature contains various rankings of interdisciplinarity, based on the interaction between the disciplines (for instance, [20–21]). Ivanitskaya

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et al. [22] proposed a four-stage interdisciplinary education model:

1. *unidisciplinarity*, in which the learner focuses on one relevant discipline and acquires unidisciplinary knowledge;
2. *multidisciplinarity*, in which the learner focuses on several disciplines but addresses each one of them separately;
3. *limited interdisciplinarity*, in which the learner integrates several disciplines around a central topic, identifies the weaknesses and strengths of the perspectives that stem from the different disciplines and, as a result, develops critical thinking skills; and
4. *extended interdisciplinarity*, in which the learner acquires meta-cognitive skills and is able to transfer the interdisciplinary knowledge to new subjects.

Advocates of interdisciplinary teaching agree that this kind of teaching is less appropriate for new learners wishing to specialize in a certain discipline, but claim that we are currently facing challenges, such as in brain science, that require interdisciplinary approaches and that modern work patterns are characterized by interdisciplinary team work [23]. In addition, they claim, the immense increase in specific disciplinary knowledge no longer enables teaching using the traditional disciplinary method, but rather necessitates a transition to a teaching method that focuses on the examination of one central idea from several different perspectives [24].

Ivanitskaya's model, as well as other studies [25–26], leads to the expectation that interdisciplinary learning will develop the learner's cognitive skills, including high-order thinking [27]. Interdisciplinary learning, compared with disciplinary learning, provides the learner with many more opportunities to relate new knowledge to previously acquired knowledge and so learning is more effective. It is also expected that interdisciplinary learning will increase the learner's motivation to learn due to the interest it sparks [27]. Evaluations of high school study programs that integrate engineering with science indicate an improvement in the students' attitudes toward science and engineering [9, 13] and an enhancement of the students' desire to continue studying these disciplines [16].

However, interdisciplinary teaching also attracts criticism that stems from a concern that such teaching focuses on the interdisciplinary aspects at the price of a more shallow treatment of the disciplinary content [28]. In addition, it is important to recognize the unique challenges posed by interdisciplinary teaching: the need to overcome the learners' natural tendency to ignore the interaction [29] and the fact that teachers who teach interdisciplinary subjects must contend with teaching a discipline (or disciplines) they were not trained to teach [30]. Thus, the development and implementation of interdisciplinary programs involve profound challenges and not all such programs will end successfully [31]. Spelt *et al.* [32] offered conditions necessary for a successful interdisciplinary program: patience, curiosity and openness on the part of the student; a syllabus that balances the interdisciplinary and disciplinary components; and teaching staff and methods that encourage learners to cooperate with their peers from other disciplines.

3. The program

The program 'Introduction to aviation weapon systems' comprised three weekly sessions, for a total of 10 study hours, and dealt with the structure and operation principle of weapon systems, such as laser-based systems and thermal systems. The teaching approach in the program was based on problem solving with the goal of demonstrating to the students how engineers work [1]. Emphasis in the sessions was placed on the affinity between the study material and aviation. The books, *Introduction to Electronic Defense Systems* [33] and *Creative Problem Solving and Engineering Design* [34], were used in the development of the program.

The program, which integrated engineering and physics, is classified as a limited interdisciplinary program [22]. In light of the challenges involved in developing interdisciplinary curricula, we carefully balanced the interdisciplinary components of the program with its disciplinary components, as illustrated in Table 1. In addition, to ensure the teacher's mastery of the different disciplines, the teacher who was selected holds advanced academic degrees in electronic engineering and in physics, and has many years of service behind him in the Israeli Air Force's technological support system.

The program began with an introductory session that included a review of mechanical waves and electric and magnetic fields, subjects that were already being studied in physics class. Next, the subject of electromagnetic waves was taught and the electromagnetic spectrum was introduced. The second session, which focused on laser-based weapon systems, addressed the physics of lasers (properties and principle of operation), radiation detectors, and aviation-engineering applications, such as laser-guided weapons. The final session dealt with thermal weapon systems. After exploring the physics of black body radiation, engineering methods for cooling detectors were described, addressing the concept of the 'signal-to-noise ratio'. Finally, the structure and operation principle

Table 1. Study contents in the program 'Introduction to aviation weapon systems'

Session	Subject	Description
1	Introduction	a. Mechanical waves (review): wave, amplitude, wavelength, period, frequency, propagation velocity* b. Fields (review): electric fields and magnetic fields* c. Electromagnetic waves* d. The electromagnetic spectrum*
2	Laser-based weapon systems	a. Properties of lasers: directionality, monochromaticity, coherence* b. Light–matter interactions: atomic energy levels, absorption, spontaneous emission, stimulated emission* c. Laser structure and principle of operation: pumping, population inversion, resonators, continuous-wave and pulsed lasers* d. Radiation detectors** e. Laser-guided weapons: structure and principle of operation, laser designators, countermeasures***
3	Thermal weapon systems	a. Black body radiation: ideal radiator, radiation laws* b. Signal-to-noise ratio** c. Methods for cooling radiation detectors** d. Heat-seeking missiles: structure and principle of operation, generations of heat-seeking missiles, countermeasures***

* Disciplinary component (physics); ** Disciplinary component (engineering); *** Interdisciplinary component.

of the various generations of heat-seeking missiles were introduced.

During the sessions, emphasis was placed on the strong affinity between physics and engineering, and the engineer's work as a problem-solver was demonstrated. Thus, for example, while describing the development process of heat-seeking missiles and the appropriate countermeasures, we used the black body radiation law. In this context, students were asked to suggest, on the one hand, countermeasures to avoid heat-seeking missiles and, on the other hand, possible mechanisms that are resistant to such countermeasures. A similar discussion was held on the subject of laser-guided weapons, in which the students were asked to suggest, based on physical principles, engineering methods to disrupt the function of such weapons.

4. Research questions

The objective of the research was to characterize students' attitudes towards the interdisciplinary program 'Introduction to aviation weapon systems' as well as changes in their attitudes towards physics and engineering. This goal led to the following research questions:

- What are the students' attitudes towards the interdisciplinary program 'Introduction to aviation weapon systems'?
- Was there any change in the students' attitudes towards physics and/or engineering during the course of the program? If yes, what is the nature of this change?

5. Methodology

The research population comprised twenty 12th graders majoring in mathematics and physics from a leading Israeli high school that is affiliated with the Israeli Air Force. The students had not been exposed to interdisciplinary teaching prior to their participation in this program.

Since the study focused on characterizing students' attitudes and on changes that they underwent during the course of the program, the qualitative methodology was selected. Both at the beginning and at the end of the study, the students were asked to fill out open-ended questionnaires. In order to complete the information obtained through the questionnaires, five semi-structured interviews were held with students at the beginning and at the end of the program. The preliminary questionnaire and interviews focused on the students' attitudes towards physics and engineering. The final questionnaire and interviews addressed the same questions and, in addition, examined the students' attitudes towards the program. The questionnaires are given in the Appendix. Finally, classroom observations were made throughout all sessions of the program. Students' comments underwent content analysis and were classified into categories. The tri-component attitude model (ABC model) served as a theoretical framework for the qualitative analysis.

6. Findings

The main findings of the research are presented below, beginning with those pertaining to students' attitudes towards the program, after which we present the change that took place in their attitudes towards physics and engineering.

6.1 Attitudes towards the interdisciplinary program

A content analysis based on the tri-component

Table 2. Attitudes towards the interdisciplinary program 'Introduction to aviation weapon systems'

Category	Sub-category	Example	Interpretation
Affective	Creating interest	'The connection between physics and engineering is very interesting. . . This is how teaching should be done in high school in order to attract more students to these subjects.' (questionnaire)	The interdisciplinary program is interesting.
	Fulfilling the need for relatedness	'The connection with the Air Force is very important to me. The program reinforced that connection because it demonstrated the use of physics in aviation.' (questionnaire)	The interdisciplinary program enhances students' feeling of belonging to the Air Force.
Cognitive	Natural choice	'The combination between physics and engineering is natural. These subjects are mutually dependent and so they should be taught in an integrated way.' (questionnaire)	Interdisciplinary teaching that combines physics and engineering is a natural choice because these disciplines are interdependent.
	Better understanding	'It [integrating physics and engineering] enables a deeper understanding... It is easier to understand the physics material through a technological application.' (interview)	Interdisciplinary teaching that combines physics and engineering leads to a better understanding of physics due to the technological context.
Behavioral	Active participation	Almost all students participated in the sessions despite the fact that they took place after lunch break. (observation)	Students showed great interest in the program, which manifested in their active participation in the sessions.
	Recommending the program	'I have already recommended it [the program] to my friends.' (questionnaire)	Students recommend the program.

attitude model yielded the categories shown in Table 2.

6.1.1 Affective component

6.1.1.1 Creating interest

In response to the question 'Why are you participating in the program?' asked on the *preliminary* questionnaire that students were requested to fill out at the beginning of the first session, most students (65%) wrote that they were participating because they had no other choice. They said: 'We were made to volunteer,' 'I was forced to do it,' 'Because it's compulsory,' or that they were participating in the program in order to please their homeroom teacher: 'The homeroom teacher asked me to do it.' Some (20%) wrote that they were participating willingly in order to gain more information about higher studies in physics and engineering: 'The program will help me decide what to study in my higher studies' and 'The program will give me an idea about what higher studies in physics and engineering are about.' A minority of students (15%) specified that interest was their reason for participating: 'Sounds interesting' and 'I am very interested in aviation weapon systems and, for the first time, the program will give me an opportunity to learn about them.'

On the other hand, in response to the question 'What do you think about the program?', which appeared on the *final* questionnaire, 90% of students (the rest of the students did not answer the question) noted that the program sparked their interest and was enjoyable: 'It was fun,' 'The program succeeded in arousing great interest in me,' and 'I wish we could study all of our subjects in such an interesting way.'

The students' enjoyment and interest can be attributed to the interdisciplinary nature of the program, which integrated physics and engineering, as revealed in the response to the question 'What do you think about integrating engineering principles into physics studies?' asked on the final questionnaire. 85% of the students (the rest of the students did not answer the question) mentioned interest: 'The connection between physics and engineering is very interesting. . . This is how teaching should be done in high school in order to attract more students to these subjects,' and 'It gives a different and interesting look at the physics that is taught in high school.' Excerpts from the students' interviews held at the end of the program support this finding:

> I like the combination [between physics and engineering] . . . Now I see the physical considerations behind the choice of this engineering solution or another when coping with heat-seeking missiles or laser-guided weapons.

6.1.1.2 Fulfilling the need for relatedness

In their response to the question 'What do you think about the affinity between the program and the Air Force?', which appeared on the final questionnaire,

80% of the students (the rest of the students did not answer the question) mentioned the enhancement of their feeling of belonging to the Air Force due to the program. A typical comment was: 'The connection with the Air Force is very important to me. The program reinforced that connection because it demonstrated the use of physics in aviation.' Support for this finding may be found in excerpts from students' interviews:

> In this program, for the first time, we have seen the applications of physics in aviation. . . This is why I now feel more a part of the Air Force.

6.1.2 Cognitive component

6.1.2.1 Natural choice

Most students (60%) believed interdisciplinary teaching of physics and engineering is not only interesting but also a natural choice, as revealed in their reply to the question 'What do you think about integrating engineering principles into physics studies?', mentioned earlier. A typical comment was: 'The combination between physics and engineering is natural. These subjects are mutually dependent and so they should be taught in an integrated way.'

6.1.2.2 Better understanding

Fifty percent of the students added in their answer to the previous question that integrating engineering principles into physics studies enables a better understanding of physics: 'Integrating physics and engineering explains the physics better.' Excerpts from the students' interviews held at the end of the program support this finding:

> It [integrating physics and engineering] enables a deeper understanding. . . It is easier to understand the physics material through a technological application.

6.1.3 Behavioral component

6.1.3.1 Active participation

The observations revealed that almost all students showed great interest in the program, which manifested in their active participation in the sessions, despite the fact that they took place after lunch break.

6.1.3.2 Recommending the program

Every one of the students (100%) gave positive answers to the question: 'Would you recommend that your friends participate in this program?' and two students (10%) even wrote: 'I have already recommended it to my friends' and 'I asked my homeroom teacher if I could continue to participate in other programs of this kind.'

6.2 Attitudes toward physics and engineering

On the *preliminary* questionnaire, the students were asked: 'What do you think about physics studies?' Analysis of students' comments revealed two components in the students' attitudes – cognitive and affective. Regarding the cognitive part, 100% of the students mentioned the great importance of physics studies: 'It is important to study physics because it is the basis for all sciences' and 'They are important because they enable us to understand the world around us'. In terms of the affective components, 65% of the students noted that physics studies were boring while the rest thought they were interesting. Excerpts from student interviews held at the beginning of the first session enable to trace the sources of the negative affective component of the majority of students:

> The studies are too theoretical and dry. . . I can't see the connection to the Air Force and it bothers me.

The students were also asked: 'What do you think about engineering studies?' Answers to this question showed that attitudes had only a cognitive component: All students claimed that engineering is important and rationalized that 'the modern world is based on engineering,' but 70% of them added that they 'have no clear concept of what it means to study engineering at university.'

In the final questionnaire, students were posed two separate questions regarding their opinion about physics studies and engineering studies. 90% of them answered that the program increased their interest in these disciplines: 'Physics interests me now,' 'The program made me want to invest more in physics and be more interested in it,' and 'I now understand what engineering is and it interests me.' About two thirds of the students added that the program enhanced their desire to study advanced physics and/or engineering: 'Thanks to the program, I am considering studying engineering' and 'Now I will want to study advanced physics and engineering'. Support for the change in the affective component of the students' attitudes may be found in excerpts from their interviews:

> The program is completely different from what I'm learning in high school. . . It's much more interesting . . . My opinion about physics studies has changed for the better since the program presented the engineering part and showed how physics is related to the Air Force.

> The program made me treat physics and engineering studies differently. . . It helped me look at the study material in a different way. . . It showed that there are interesting fields in these subjects and that it can be really fun to study them. . . This is why my desire to study higher physics and engineering has become stronger.

In addition to changes in the affective component described above, about one third of the students exhibited enhanced recognition of the importance of physics and engineering in general, and in the Air Force in particular. A typical comment was: 'Only

Table 3. Post attitudes toward physics and engineering

Category	Sub-category	Example	Interpretation
Affective	Increased interest	'The program made me treat physics and engineering studies differently. . . It helped me look at the study material in a different way. . . It showed that there are interesting fields in these subjects and that it can be really fun to study them.' (interview)	Following the program, students' interest in physics and engineering increased.
	Increased desire to continue with higher studies	'Now I will want to study advanced physics and engineering.' (questionnaire)	Following the program, students' desire to continue with higher studies in physics and engineering increased.
Cognitive	Enhanced recognition of the importance of physics and engineering	'Only now, thanks to the program, have I understood that physics and engineering are so important and are the basis of the Air Force's strength.' (questionnaire)	The program sharpened students' perception of the importance of physics and engineering.

now, thanks to the program, have I understood that physics and engineering are so important and are the basis of the Air Force's strength'.

The post attitudes toward physics and engineering are summarized in Table 3.

7. Discussion

On the affective level, according to the findings, students exhibited a great deal of interest in the program and reported enjoying the sessions. This results from both the integration of physics and engineering and the connection made between these disciplines and aviation. The emphasis placed during the sessions on the affinity between the study material and the Air Force, to which the students belong, fulfilled their need for relatedness. Thus, according to the self-determination theory [35], students' intrinsic motivation was enhanced, resulting in interest and enjoyment. Indeed, most students participated in the first session for lack of choice (external regulation) or from a desire to fulfill their teacher's expectations (introjected regulation). In the last session, however, 90% of students were motivated by considerations of interest (intrinsic motivation). It should be mentioned that, in their research on university student retention, Watson *et al.* [36] noted the importance of a personal affinity to the study subjects. Our findings, according to which the students took an active part in the sessions, are consistent with the findings on the affective level.

The research also shows that, following the program, the students' interest in physics and engineering increased, as did their desire to continue with higher studies in these fields. These findings are consistent with findings of other studies on high school interdisciplinary programs that indicated an improvement in the students' attitudes towards science and engineering [9, 13, 15] and an increase in students' desire to continue studying these subjects [16].

In terms of the cognitive aspect, the research indicates that the program sharpened students' perception of the importance of physics and engineering in general, and in the Air Force in particular. A similar finding was obtained in a study that examined characteristics of a US Air Force introductory engineering course [37]. According to its participants' testimonies, the course succeeded in 'opening the students' eyes' in all that pertains to the importance of engineering in general, and engineering in the Air Force in particular. Nevertheless, it is important to remember, in the context of this comparison, that the said course was aimed at students in their first year of engineering studies, whereas the program described in the present paper was attended by students in their final year of high school (12^{th} graders).

The theoretical contribution of the research is in the characterization of the attitudes of aviation high school students towards the interdisciplinary study of aviation weapon systems. To the best of our knowledge, this is the first time such work has been done. The practical contribution of this study may be seen in the implementation of the research findings when designing study programs in such fields. Despite the relatively small sample size in this study, these potential contributions are strongly validated in light of the shortage in engineering professionals [10–11] and the many efforts made to attract high school graduated to these fields [9].

It is our intention to perform further research to see how many of the program graduates indeed continued with higher physics or engineering studies and to examine the relative weight of the program in their academic choices. In addition, in light of the students' attitude that interdisciplinary teaching that integrates physics and engineering leads to a better understanding of physics, we plan to examine whether students' participation in the program was indeed reflected in their performance in their high school physics studies.

8. Conclusions

The interdisciplinary program 'Introduction to aviation weapon systems' aimed to enhance the students' interest in physics and engineering and encourage them to continue with advanced studies in these disciplines. The objective of the research described here was to characterize students' attitudes towards the program, as well as the changes in their attitudes towards physics and engineering following the program.

The research results reveal that on the cognitive level students believe that interdisciplinary teaching that combines physics and engineering is natural and leads to a better understanding of physics. On the affective level, students exhibited a great deal of interest towards the program and enjoyed the sessions. The research also shows that the program sharpened students' perception of the importance of physics and engineering in general, and in the Air Force in particular. Finally, following the program the students' interest in physics and engineering increased, as did their desire to continue with more advanced studies in these areas.

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Appendix – Preliminary and final questionnaires

Preliminary questionnaire

- What do you think about physics studies?
- What do you think about engineering studies?
- Why are you participating in the program?

Final questionnaire

- What do you think about physics studies?
- What do you think about engineering studies?
- What do you think about the program?
- What do you think about integrating engineering principles into physics studies?
- What do you think about the affinity between the program and the Air Force?
- Would you recommend that your friends participate in this program?

Aharon Gero holds a BA in physics, a BSc in electrical engineering, an MSc in electrical engineering, and a Ph.D. in theoretical physics, all from the Technion – Israel Institute of Technology. In addition, he has an MBA from the University of Haifa, Israel. He is a faculty member at the Department of Education in Technology and Science of the Technion. His research focuses on electrical engineering education and interdisciplinary education that combines physics with electronics, such as electro-optics and microelectronics education.