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Promoting Systems Thinking in Two-Year Technology Students: An Interdisciplinary Course on Medical Ultrasound Systems*

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The development of systems thinking is a primary goal of engineering and technology education, especially within the framework of Industry 4.0. While many actions are being taken to promote systems thinking among engineering students, the efforts to advance it among students in two-year technology programs are relatively few. With the objective of promoting systems thinking among electronics students at a two-year college, a unique course on medical ultrasound systems was recently developed. This interdisciplinary course combined physics, electronics and medicine. The study described in this paper characterized, using both quantitative and qualitative tools, students' attitudes toward the course and changes in their systems thinking. Seventeen electronics students in their second semester of study participated in the research. Results point to a significant improvement in students' systems thinking. As to attitudes toward the course, students believe that the course raised interest, advanced systems thinking and contributed to their professional development, but also increased the academic workload immensely.

Keywords: systems thinking; interdisciplinarity; two-year colleges; students' attitudes; ultrasound systems

1. Introduction

Systems thinking deals with the ability to comprehend the interrelations and synergy between the system's components [1]. Due to the continually increasing complexity of engineering systems, the need for systems thinking has grown in significance [2]. This importance is even expected to increase as part of the fourth industrial revolution, one of the cornerstones of which is cyber-physical systems [3, 4]. Therefore, substantial efforts are being undertaken in engineering education to impart systems thinking skills to engineering students [5, 6] and even high-school students [7, 8]. However, activities to develop it among students in two-year technology programs are relatively limited.

As one of the tools for promoting systems thinking is system analysis [9], a course on medical ultrasound systems was recently developed for electronics students enrolled in a two-year program at an Israeli college. This interdisciplinary course combined physics, electronics and medicine, and was intended to develop systems thinking. It should be noted that courses on this topic are offered as part of associate degree programs aimed to train ultrasound systems operators [10]. The course developed within the framework of the current study differs in that it was not intended to certify its graduates as ultrasound technicians; rather, as mentioned above, to promote their systems thinking.

The study described in the paper characterized, using quantitative and qualitative instruments, students' attitudes toward the course and changes in their systems thinking. To the best of our knowledge, such a characterization was done here for the first time. The study's findings and conclusions may expand the relatively small body of knowledge on this subject and improve the training of students in two-year technology programs.

The paper opens with a theoretical background reviewing the two topics on which the research is based on, systems thinking and interdisciplinary education. Next, the Medical Ultrasound Systems course is described, followed by the research objective and methodology. A discussion of the main findings concludes the paper.

2. Theoretical Background

2.1 *Systems Thinking*

Systems thinking focuses on the ability to understand the interdependence and synergy between the system's components [1]. In this manner, it differs in principle from the reductionist approach which claims that one can limit him or herself for studying the characteristics of each component separately [11].

In light of the continually increasing complexity of engineering systems, systems thinking is gaining a more primary role in engineering and technology education [2]. This significance is reinforced within the Industry 4.0 concept, which is founded on

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cyber-physical systems, Internet of Things and big data [3, 4].

Most scholars agree [6, 12–14] that the main features of systems thinking are:

- Seeing the entire system beyond its components;
- Understanding the system's operation without a need for all details;
- Comprehending the interrelations and synergy between the system's components;
- Considering nontraditional engineering factors, e.g., financial and organizational factors.

Under the assumption that systems thinking can be learned [14], various ways for improving systems thinking skills have been proposed, e.g., expert presentation, computer simulation and analysis of "real-world" systems [9]. Research suggests that systems thinking develops hierarchically, with the skills developed at a certain stage form the basis for skills acquired at the next level. At first, the student identifies the system's components and the process taking place within it. Then, he or she understands the interrelations between these components. Finally, the student recognizes the periodicity of the system and is able to investigate the functioning of the system against time [15].

In engineering education, many efforts have been undertaken to develop systems thinking among undergraduate students [6, 16] and even earlier [7, 17]. The scope of such activities varies, starting with specific courses with the goal of teaching systems thinking skills [6] and up to four-year training programs [18]. Thus, for instance, the authors of [16] developed a design course for sophomore mechanical engineering students, focusing on target product specifications, concept generation and systems architecture. Similarly, the authors of [17] developed a high-school course on engineering design dealing with a real-time control system for an electric motor.

Studies conducted among electrical [5], mechanical [16, 19] and industrial engineering students [20] reveal that systems thinking can be learned. In contrast, the efforts to promote and assess systems thinking among students enrolled in two-year technology programs are relatively limited.

2.2 *Interdisciplinary Education*

Interdisciplinarity is usually defined as the integration of knowledge of at least two different disciplines [21]. It is important to emphasize that the synthesis of knowledge is the distinct characteristic of interdisciplinarity as compared to multidisciplinarity, in which a number of knowledge fields are indeed represented, but without any integration between them [22].

From the cognitive perspective, interdisciplinary programs provide many opportunities for the student in which he or she can connect new knowledge to knowledge previously acquired, certainly in comparison to disciplinary programs. Therefore, according to Piaget's Theory of Cognitive Development [23], it is expected that interdisciplinary programs would develop higher-order thinking skills [24], including critical thinking [25] and systems thinking [8]. From the affective standpoint, interdisciplinary programs increase academic motivation due to the interest they raise [8, 26, 27].

Alongside these advantages, it is also important to recall the claims made by critics of interdisciplinarity. They contend that this form of education focuses on interdisciplinary aspects permitting only a superficial review of the disciplinary contents. Moreover, frequently educational programs aspiring to interdisciplinarity are actually multidisciplinary, namely, lacking the synthesis between the various topics [28]. The conclusion is that there are considerable challenges in the development of interdisciplinary programs and their implementation, and that not all will end in success.

According to the authors of [28], the salient conditions needed for the success of interdisciplinary programs are curious, open and patient students; teachers' involvement in curriculum development; balanced curriculum; and, finally, support and resource allocation from management.

Over the years, interdisciplinary programs have been developed on a number of topics, such as robotics [29], aerospace [30, 31] and nanotechnology [32, 33]. Some were intended for high-school students [30, 33] and others – for university students [29, 31]. An evaluation of these programs shows that most have contributed to students' understanding and interest.

Experts are of the opinion that in the current digital age, characterized by a notable interpenetration of science and engineering, the educational significance of interdisciplinary programs combining science and engineering (or technology) will continue to grow. This is because such programs are able to provide their students with a skills set relevant for the times we live in [34, 35].

3. Medical Ultrasound Systems Course

The course at the focus of this study, Medical Ultrasound Systems, was developed for electronics students in their second semester of study at a two-year college in Israel. A two-year college is a post-secondary educational institution providing mostly practical training in a variety of technology fields, such as electronics, mechatronics and biotechnology. Most students enrolled in such a college attain relatively low academic achievements or are part of the socioeconomic periphery [36]. It should be noted that the characteristics of students in two-year colleges in Israel are similar to those in American colleges granting an associate degree [37].

The electronics program is intended to provide students with knowledge and skills in three fields: analysis and design of analog and digital circuits, writing and developing software and designing embedded systems. During the first year, students complete basic courses in electronics. The second year is dedicated to advanced subjects and to the final project.

The interdisciplinary Medical Ultrasound Systems course is comprised of eight weekly sessions of two hours each. The teaching method is front facing. At the end of the course, the student should be able to:

- Explain basic terms in wave physics;
- Explain the piezoelectric effect;
- Explain the principle of operation of ultrasound systems and their application in medicine;
- Identify the components of medical ultrasound systems and analyze the interrelations between them;
- Identify electronic subsystems and explain their principle of operation;
- Describe other medical imaging methods and compare the advantages and disadvantages to those of ultrasound systems.

In line with Bloom's taxonomy (cognitive domain) [38], the learning outcomes refer to both lower- (understanding) and higher-order thinking (analysis and evaluation). The inclusion of the latter stems from the finding, mentioned above, that one of the tools for developing systems thinking is system analysis [9].

At first, the course focuses on basic terms in wave physics, such as longitudinal and transverse waves, amplitude, wavelength, frequency, propagation speed, and reflection, transmission, and absorption (2 hours). Next, the course discusses the characteristics of sound waves in general and ultrasonic waves in particular, e.g., speed of sound and acoustic impedance (1 hour). The next part (2 hours) deals with the piezoelectric effect and discusses the structure and principle of operation of piezoelectric transducers (matching layers, quality factor and near and far acoustic fields). Then, the structure and the operation modes of medical ultrasound systems (A, B and M Modes) are described, with an emphasis on the interrelations between the system's components (4 hours). The next section focuses on a number of electronics subsystems, e.g., the amplifier of the echo signal, Schmitt comparator and the display unit (5 hours). At the end of the course, other medical imaging methods, such as x-ray, CT, MRI and endoscopy are reviewed, including their advantages and disadvantages compared to those of ultrasound systems (2 hours). The course development was inspired, inter alia, by the book *Fundamentals of Medical Ultrasonics* [39].

During the development of the course, an attempt was made to meet the conditions necessary for the success of interdisciplinary programs (Section 2.2). Thus, a balance was maintained between the disciplinary (physics, electronics and medicine) and interdisciplinary components (medical ultrasound systems) of the curriculum. The course instructor, who led the development team, had a BSc in electrical engineering and academic training in medical ultrasonics, as well as many years of experience in teaching college electronics. Finally, the development of the course was supported by management.

4. Research Goal

The study characterized students' attitudes toward the Medical Ultrasound Systems course and changes in their systems thinking.

The following questions were formulated:

- What are students' attitudes toward the course?
- Did a change occur in students' systems thinking? If so – what are the characteristics of this change?

5. Methodology

5.1 Participants

Seventeen electronics students (second semester of study) at a leading Israeli two-year college attended the Medical Ultrasound Systems course and took part in the study. The students' age range was 18–20, and none had been previously exposed to interdisciplinary courses. Participants' characteristics were similar to those of students who usually enrolled in the electronics program.

5.2 Procedure

The study made use of quantitative and qualitative tools with the purpose of increasing the findings' trustworthiness and allowing the presentation of various aspects of the phenomenon being studied [40].

The participants filled out an anonymous closed-ended questionnaire at the beginning and end of the course. This self-reporting questionnaire focused on systems thinking. Upon completion of the course, students answered an anonymous open-ended questionnaire dealing with their attitudes toward the course. The class was observed throughout the course. These observations focused on the behavioral component of students' attitudes (e.g., class attendance and participation).

Quantitative data were statistically analyzed and the corresponding effect size (Cohen's *d*) was calculated. Since the questionnaire was anonymous, it was impossible to perform a statistical analysis based on repeated measures. Therefore, according to literature [41], the systems thinking scores at the beginning of the course and those upon its completion were assumed to be independent, and an unpaired *t*-test, which has a lower power, was performed. For the same reason, the correlation between these scores could not be determined. Thus, the effect size provides a conservative estimation [42].

Two engineering education experts coded the qualitative data and categorized them using directed content analysis [43]. The analysis was based on the three-component attitude model (ABC model) [44] and the major features of systems thinking discussed in Section 2.1.

5.3 Tools

The self-reporting questionnaire used for evaluating students' systems thinking was a five-level Likert-like scale, ranging from "completely disagree" to "completely agree". The questionnaire was based on the Capacity for Engineering Systems Thinking (CEST) scale [45], adjusted for two-year technology students. The questionnaire included twenty statements representing the main characteristics of systems thinking, as described in Section 2.1. Thus, for example, the statement, "when I am responsible for the development of a specific system component, I do not need to concern myself with the remaining components which are not my responsibility to develop", reflects a relatively low level of systems thinking, whereas the statement, "when I am responsible for the development of a specific system component, it is important that I familiarize myself with the needs of the customer", expresses a relatively high level of systems thinking. The statements were validated by two engineering education experts. Cronbach's alpha (0.80) attests to good internal consistency. A sample of the statements is provided in Appendix A. A sample of the questions of the open-ended questionnaire is given in Appendix B.

6. Findings

Below are the main findings of the study. We initially describe the findings related to students' attitudes toward the course, and then, those addressing systems thinking.

6.1 Attitudes

An analysis of students' answers in the open-ended questionnaire and an analysis of the observations, identified cognitive, affective and behavioral components in students' attitudes toward the course.

From the cognitive perspective, students found both advantages and disadvantages in the course. Regarding the advantages, students are of the impression that the course advances their systems thinking:

> "I believe this [the course] is an excellent idea, since it teaches you how to look at a system. . . It doesn't make sense to teach somebody one part and then he or she doesn't understand how that part interacts with the others."

In their opinion, the course improves understanding of electronics:

> "The course can also help in the understanding of electronics itself because of the context [ultrasound systems] in which it is taught."

it enriches knowledge:

> "The course enriches knowledge and teaches about ultrasound systems."

and prepares for future career:

> "In my opinion, it [the course] is more important than other courses, such as mathematics that I don't know what it's good for. . . This [the current course] gives you something – how to analyze systems – you can get a lot out of in the future."

At the same time, students are of the opinion that the course considerably increases their academic workload:

> "The course makes it difficult for us because there is already a huge workload during the [second] semester [of the program]."

and that it was not allocated enough time:

> "[The worst thing about the course was that] there wasn't enough time."

Table 1 summarizes the cognitive component of students' attitudes toward the course.

In the affective domain, students found interest and pleasure in the course for a number of reasons. First, because of its interdisciplinary nature:

> "The course was interesting. . . I like this concept where we're not only studying electronics, but also combining physics and other fields."

Second, due to addressing system-wide considerations:

> "[The most interesting lesson in the course was] the lesson in which we learned about the electronic structure of an ultrasound system. This [the lesson] was interesting because I knew I wasn't just learning about the flip-flop [electronic circuit], but rather, I'm learning about it because it's part of a system."

Table 1. Interdisciplinary course on medical ultrasound systems: Students' attitudes (cognitive component)

Category	Subcategory	Example	Interpretation
Strengths	Promoting systems thinking	"Thanks to the course, now I understand that each component is designed according to the other components and not separately."	The course advances students' systems thinking
	Improving understanding of the disciplines	"The course helped me to better understand electronics."	The course improves understanding of electronics
	Knowledge enrichment	"I would recommend this course to my friends because it enriches knowledge."	The course enriches students' knowledge
	Contribution to professional development	"The course prepared us for next year's project, in which we design a product." "[The best thing about the course is that it] prepares me for my future career."	The course prepares students for their continuing studies and future career
Weaknesses	Academic workload	"The course makes it difficult for us because we already have a heavy workload."	The course increases students' workload
	Lack of time	"It's a shame there wasn't enough time."	Not enough time was allocated for the course

Table 2. Interdisciplinary course on medical ultrasound systems: Students' attitudes (affective component)

Category	Subcategory	Example	Interpretation
Generating interest and pleasure	Interest due to the integration of knowledge fields	"It [the course] didn't focus on one topic but a few topics, and that was interesting."	The course generates interest by integrating a number of knowledge fields
	Interest due to addressing system-wide considerations	"[The most interesting class was] when we spoke of the interactions between the various system components."	The course generates interest by addressing system-wide considerations
	Pleasure due to expanding horizons	"I like the course. It was fun because we learned a lot of new things."	The course generates pleasure by expanding horizons

Table 3. Systems thinking scores

Test	*M*	*SD*
Pretest	66.75	4.77
Posttest	70.82	7.58

And, finally, because it expanded one's horizons:

> "I enjoyed learning about things I'm not used to learning about here in college."

Table 2 presents the affective component of students' attitudes toward the course.

Behaviorally, all students attended classes and most of them actively participated despite the inconvenient hour (early morning) during which the course was held.

6.2 Systems Thinking

Table 3 displays students' systems thinking score (mean M, ranging between 20 to 100, and standard deviation SD) at the beginning of the course (pretest) and at its end (posttest). A t-test indicates significant improvement ($t(26) = 1.87$, $p < 0.05$), characterized by a medium effect size ($d = 0.64$).

An analysis of students' answers in the open-ended questionnaire (Table 4) shows that at the end

Table 4. Systems thinking characteristics among students (end of course)

Characteristic	Examples	Interpretation
Seeing the entire system	"When I design a component of a product, I should see the whole picture." "It is not wise to design a very good component if the other parts of the product are not good enough."	Seeing the whole system is required in order to design individual components
Comprehending the interrelations between the system's components	"[We realized that] every component should fit with the others." "[We understood that] each component should be designed according to the other parts."	It is important to understand the interrelations between the system's components
Ability to consider nontraditional engineering factors	"[We realized that] there are cost-benefit considerations that influence design." "I should design according to the financial resources at my disposal."	Economic considerations should be taken into account

of the course they began adopting some of the systems thinking features mentioned in Section 2.1.

7. Discussion

This paper presented an interdisciplinary course on medical ultrasound systems intended to promote systems thinking among students at a two-year technical college. The study characterized students' attitudes toward the course and examined changes in their systems thinking.

The study identified affective, behavioral and cognitive components in students' attitudes. From the affective perspective, students found interest in the course deriving from three factors: combining disciplines (physics, electronics and medicine), addressing system-wide considerations, and knowledge enrichments. This finding was congruent with the behavioral aspect of the attitude, according to which students attended classes and actively participated, despite the inconvenient hour at which the course was held.

The findings indicating the existence of intrinsic motivational factors (arising from interest and pleasure) are of great importance. The reason is that electronics studies require higher-order thinking skills, and intrinsic motivation plays a key role in their development [46]. These findings are even more significant in view of the results of previous research, suggesting that some two-year college students are mainly driven by extrinsic motivational factors, e.g., meeting family expectations [47].

The positive feelings toward the course are in line with the results of studies concerning interdisciplinary programs that combine science and engineering (or technology) [8, 31, 48]. These studies show that "real-life" examples from students' field of knowledge (such as electronic subsystems of medical ultrasound systems discussed here) create interest among students and thus strengthen their intrinsic motivation. Thus, for instance, attitudes similar to those found here were identified among software engineering students who attended a course that incorporated scenarios taken from industry [49]. The explanation for this stems from self-determination theory, according to which examples from students' field of knowledge or future field of practice may satisfy their need for relatedness, thus cultivating their intrinsic motivation [50].

In the cognitive domain, students think that the integration of knowledge fields may improve the understanding of the disciplines themselves. This finding reinforces previous results, according to which students believe that interdisciplinary learning of science and engineering improves understanding due to the engineering context [30, 33]. At the same time, the counter-argument should be mentioned, according to which interdisciplinary teaching sometimes tends to superficially address disciplinary contents [28].

Additionally, students believe that the course prepared them for their continuing education and future career, and, therefore, contributed to their professional development. It can be concluded from this that aside from interest (intrinsic motivation), students are also driven by beneficial considerations (identified regulation). It is important to note that in light of self-determination theory [50], these motivational factors, and especially intrinsic motivation, indicate a high degree of autonomous motivation among students. These findings are reinforced in view of the considerable workload created by the course.

Finally, students are of the opinion that the course promoted their systems thinking. The findings show that upon conclusion of the course, the students' systems thinking score was indeed significantly higher (medium effect size) than at the start. It was also found that at the end of the course students began adopting some of the characteristics of systems thinking described in [6, 12–14]. Thus, for instance, students realized the importance of seeing the whole system and recognized the need to understand the interactions between the various components and factor in nontraditional engineering considerations. The improvement in students' systems thinking can be attributed to the course's emphasis on the interdependence between the system's components. This improvement is congruent with the results of earlier studies showing that systems thinking of high-school [15, 17] and engineering students [6, 16] can be developed.

The research faced two primary limitations: (a) a relatively small number of participants, and (b) the absence of a control group. Both limitations were a result of the relatively small number of electronic students in their second semester of study. Thus, creation of a reasonably sized control group was not possible. In order to overcome these limitations and with the objective of increasing the findings' trustworthiness, we made use of qualitative instruments alongside quantitative ones [40].

The study's theoretical contribution lies in the characterization of the change taking place in systems thinking among students at a two-year college enrolled in an interdisciplinary course. To the best of our knowledge, this is the first time such a characterization has been conducted. The practical contribution may be expressed in the implementation of the findings for the purpose of advancing systems thinking among technology and engineering students. For this purpose, we recommend creating an interdisciplinary course focusing on systems analysis, similar to the one described here, and making sure to allocate enough time for it. We also recommend scheduling the course during a semester in which the workload is not as high. Such a course could, for example, deal with food production systems (combination of chemistry, biotechnology and industrial engineering) or cranes (physics, mechanical engineering and civil engineering) [51, 52]. We are of the opinion that such contributions are reinforced in light of the importance of systems thinking, especially as part of the fourth industrial revolution [3], and in view of the limited activity to advance it among students in two-year technology programs.

8. Conclusions

The study characterized electronics students' attitudes toward the course "Medical Ultrasound Systems" and changes in their systems thinking. The results indicate significant improvement (medium effect size) in systems thinking among students participating in the course. It has also been found that upon completion of the course students began adopting some of the characteristics of systems thinking. Students were of the opinion that while the course was interesting, advanced systems thinking and prepared them for their continuing studies and future career, it also considerably increased their workload.

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Appendix A – Closed-ended Questionnaire

The self-reporting questionnaire used for evaluating systems thinking, described in Section 5.3, was a five-level Likert scale based on the Capacity for Engineering Systems Thinking (CEST) questionnaire [45]. The questionnaire included 20 statements. Following is a sample of the statements. Statements 2 and 5 reflect a relatively high level of systems thinking, while the remaining statements represent a relatively low level of systems thinking.

1. The economic aspects of a project are only the concern of the project manager.
2. When I am responsible for the development of a specific system component, it is important that I familiarize myself with the needs of the customer.

3. When I am responsible for the development of a specific system component, I do not need to concern myself with the remaining components which are not my responsibility to develop.
4. When I am responsible for developing the hardware, it is better that others deal with the integration of the hardware I am developing with the software (that someone else is writing).
5. When I am responsible for developing a specific system component, it is important that I identify the advantages inherent in integrating "my" component with the remaining components which are not my responsibility to develop.

Appendix B – Open-ended Questionnaire

Below is a sample of questions from the open-ended questionnaire described in Section 5.3:

1. What is your opinion of the course? Explain.
2. (a) Describe the most interesting class.
   (b) What was interesting about it?
3. What, in your opinion, is the best thing about the course? Explain.
4. What, in your opinion, is the worst thing about the course? Explain.

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