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Animation Based Learning of Electronic Devices

AHARON GERO

WISHAH ZOABI
Technion - Israel Institute of Technology
Haifa, Israel

AND

NISSIM SABAG
ORT Braude College
Karmiel, Israel

ABSTRACT

Two-year college teachers face great difficulty when they teach the principle of operation of the bipolar junction transistor – a subject which forms the basis for electronics studies. The difficulty arises from both the complexity of the device and by the lack of adequate scientific background among the students. We, therefore, developed a unique learning unit based on computer animation that was tailored to the students' background and qualitatively describes the processes occurring in the transistor. The current research examined the characteristics of the above learning among students at a leading Israeli two-year college. The research, which used quantitative instruments alongside qualitative ones, indicates a significant gap between the achievements of students who studied the subject of the transistor through animation and the achievements of their peers who learned it using static diagrams. Additionally, students who studied the subject through animation express significantly more positive attitudes towards electronics than their peers.

Key Words: Electrical engineering education, animation based learning, attitudes towards electronics

INTRODUCTION

A Practical Engineer is a technology oriented professional, who occupies a position in industry that is intermediate between the engineer and the technician. After two years in specialized colleges, practical engineers integrate into various industrial fields such as biotechnology, electronics, software and more. The training of practical engineers is focused on the practical aspect of the profession and less on its theoretical one; therefore practical engineering courses constitute learning opportunities for students in a relatively low level of achievement, who do not aspire for academic studies [1]. However, the Israeli industry needs skilled practical engineers and reports a shortage of some 400 professionals, mainly in the field of electronics [2].

Practical engineering college teachers face great difficulty when they teach advanced physical subjects in general, and the principle of operation of the bipolar junction transistor[1] (BJT) in particular – a subject which forms the basis for electronics engineering studies and is being taught during the first semester. The difficulty arises from both the complexity of the device [3] and lack of adequate mathematical and physical background among the students [4]. These students, continuing their technological training in electronics – a major they began in high-school – have no knowledge of physics, even on high-school level. Furthermore, their knowledge of mathematics is minimal. Therefore, they have difficulty comprehending basic terms and processes in semiconductor physics such as holes, drift and diffusion. These concepts, however, are vital for understanding the BJT operation principle. Unlike undergraduate physics students who have strong background in mathematics but still need visualizations for conceptual understanding of abstract scientific phenomena [5], practical engineering students can hardly understand abstract concepts and phenomena without visualizing them. However, most of the teachers settle for analyzing the transistor characteristics as a component in a circuit and do not deal with its internal structure and the principle of operation. The result is, therefore, that students focus on the technical solution of problems without understanding the underlying physical principle. Informal conversations with teachers of these students indicate that this level of education essentially harms the students' future ability to deal with advanced topics in electrical engineering, as expressed in their poor final scores of around 65/100 on advanced courses. Furthermore, in order to enable graduates to find jobs in the Israeli high-tech industry following graduation, they are required to comprehend the BJT operation principle.

Therefore, we developed a new learning unit based on computer animation that was *tailored* to the practical engineering students' background and qualitatively describes the processes occurring in the transistor. Such unit was developed, to the best of our knowledge, for the first time. The research, described below, examined the academic achievements and attitudes of students who studied this unit.

The paper is organized as follows. We start with a theoretical review of the two subjects the study relies upon: animation based learning and problem solving taxonomy. Next, we describe the new learning unit, developed by the authors, and present the research questions and methodology. Finally, the findings are discussed and further research directions are suggested.

1 A bipolar junction transistor (BJT) is an electronic device constructed of semiconductor material.

THEORETICAL FRAMEWORK

Animation Based Learning

Animation is designed to provide the illusion of movement on the screen. According to Mayer and Moreno [6], animation includes three components: picture – animation is a pictorial representation, motion – animation describes a visible motion, and simulation – animation contains objects created artificially by drawing or other simulation technique. The advantage of animation is particularly evident in cases in which it is hard to demonstrate processes in classroom lessons or even in a laboratory [7].

The cognitive theory of multimedia learning [8, 9] is one of the most comprehensive theories dealing with multimedia based learning in general and instructional animations in particular. The theory assumes the following:

a) Dual channel – information is processed through two separate channels: a channel processing auditory – verbal information, and a channel processing visual – pictorial information;
b) Limited capacity – information processing capabilities in each of the two channels are limited;
c) Active processing – the learning process involves substantial cognitive processing in each of these channels. The processing includes paying close attention to the material taught, its organization into a coherent structure and integration into the existing knowledge.

These assumptions underlie the Dual Coding Theory of Pavio [10], the Working Memory Theory of Baddeley [11], the Cognitive Load Theory [12], and the Generative Learning Theory of Wittrock [13].

Based on these assumptions and extensive empirical studies, Mayer and Moreno [6] offered several principles of animation design, which may foster meaningful learning:

a) Multimedia principle – animation is combined with narration;
b) Spatial contiguity principle – animation and the accompanying written text appear side by side;
c) Temporal contiguity principle – animation and accompanying narration appear simultaneously (rather than sequentially);
d) Coherence principle - animation does not include extra words, pictures or sounds;
e) Personalization principle - narration is not formal but makes use of the first and second persons.

Principles of animation design, some of which overlap the above principles, are also proposed by [14–16]. For example, Kali and Linn [14] supported the combination of a number of representations of the phenomenon such as animation and narration (multimedia principle) and emphasized the need to avoid extra items in animation which distract the learner from the main subject (coherence principle).

There is an ongoing debate in literature over whether the use of computer animation is preferable to traditional teaching methods [17]. Supporters of the static hypothesis [18, 19] argue that better learning is achieved by using written text and static diagrams. They claimed that a) learning by using static methods allows the learner to control the pace of learning and thus help him/her to regulate the intrinsic processing and prevent the development of an overload; b) static tools present only the key stages of the process learned and hence the learner can focus on the most important information and thus reduce the extraneous processing; and c) static measures stimulate the learner to discover the existing differences between a given diagram to the one that follows, and that makes the student involved in germane processing, leading to more significant learning. In contrast, proponents of the dynamic hypothesis [20–22] argue that the use of computer animation accompanied by explanations is the one that leads to better learning. They argued that, compared to the use of static measures, animation actually reduces the extraneous load imposed on the learner – a load resulting from the need to build a dynamic picture necessary to understand the process learned. In addition, the animation creates interest leading to the student's motivation to invest more effort in understanding the material being studied, and that encourages him/her to be involved in germane processing. It should be noted that studies have not thus far produced any conclusive and consistent results clearly indicating the advantages of one approach over another [17, 23]. However, it appears that animation indeed has many advantages, provided it is properly integrated into the teaching process [24–26].

In view of the substantial cognitive resources required to process complex animations, recent studies relate to cueing, i.e., emphasizing relevant regions of an animation in order to direct the learner's attention to them. One approach to cueing focuses on manipulation of the visuospatial features of animation, including use of arrows [27], luminance contrast [28] or use of spreading color cue, demonstrated in an animation that describes the mechanism of a piano [29]. Another alternative, temporal scaling, deals with pre-designed modification of the animation presentation speed, with intent to simultaneously display processes characterized by different time scales, like the ones in a pendulum clock [30]. The findings regarding the effectiveness of cueing are mixed [31]. While cues that direct the learner to specific locations within the animation are effective and help the learner select relevant information, they do not necessarily assist the learner to identify causal relations [31]. Therefore, additional study that will help learners process complex animations in a more efficient way is required [32].

A major issue of animation based learning is the split-attention effect [33]. The learner is sometimes required to split his/her attention between text and illustrations, and is not always able to integrate them. A possible solution to this problem is the spatial contiguity principle [6], mentioned above. Another strategy is color coding that uses a particular color to connect elements that appear in the text to those within the pictures. Studies indicate improvement in the learner's retention and transfer performances following the use of this strategy in animations relating to biochemistry [34]. Recently, the effect of visual presence of an animated pedagogical agent (APA) on learning was examined [35]. APA is a lifelike character that appears on the screen and focuses the learner's attention to relevant visual information in multiple-representation environments. Findings attest to APA's contribution to the learning process in mathematics [35], physics [36], and biology [37].

Animation serves as a model to the physical process described through it. There is fear, therefore, that learners will develop misconceptions because of the simplistic interpretation of the animation [38]. Thus, the teacher should accompany the animation with verbal explanations in order to clarify its limitations [39] and discuss the discrepancies between the animation displayed and his/her explanations [40]. Additionally, the teacher has to call the students' attention, by using his/her verbal explanations, to key details in the animation they might miss because of the load [41].

Animations dealing with electronic devices at university level have been developed with the expectation that they will help students in understanding the processes occurring in semiconductors [42] and even increase the students' interest in these processes [43]. Thus, Lundgren and Jonsson [44] developed animations, for electrical engineering students in their second year of studies, focusing on the processes of drift and diffusion in semiconductors, and found a remarkable improvement in the interest shown by students, but not in their level of understanding. Recently, Sihar and colleagues [45] developed an animation based course on semiconductor devices for physics students in the last year of their studies. They reported improved student achievements as well as positive attitudes toward learning. It is important to stress that the research population of the above mentioned studies included students studying towards a first degree in engineering or physical sciences. This population differs substantially from practical engineering students characterized above by a relatively low level of achievement and no aspiration for academic studies [1]. Unlike previous research, this study dealt with practical engineering students and compared the academic achievements and attitudes of students, who studied the subject of the BJT through animation, to those of their peers who studied it using static diagrams drawn on the blackboard.

Problem Solving Taxonomy and Higher-Order Thinking

Problem solving taxonomy [46] was offered as an alternative to Bloom's well-known taxonomy in the cognitive domain [47]. It was argued that Bloom's taxonomy is inconvenient for use in the case of problem solving, since a typical activity in problem solving, such as diagnosis of the problem, combines the first three of Bloom's levels, i.e., knowledge, comprehension and application, together [46]. Problem solving taxonomy classifies the activities involved in problem solving into five categories: routine, diagnosis, strategy, interpretation and generation, defined as follows:

a) Routine – a procedure that the student knows well;
b) Diagnosis – selecting the appropriate procedure known to the student;
c) Strategy – selecting the most appropriate procedure to solve a problem that can be solved in a number of ways;
d) Interpretation – translation of a real world problem to data enabling the use of procedure;
e) Generation – developing a procedure that is unfamiliar to the student.

For example, calculating the equivalent resistance of two resistors is a routine activity. Selecting Kirchhoff's current law or the alternative voltage law in order to calculate the voltage across a resistor in a complex electrical circuit is an example of strategy.

Resnick [48] and Zohar and Dori [49] distinguished between lower-order thinking skills, characterized by memorizing and understanding, and higher-order thinking skills that require more complex cognitive activities, such as posing questions, inquiry, solving problems, and drawing conclusions. These higher-order thinking skills require multiple solutions – each with its own advantages and disadvantages – and involve uncertainty. In accordance with this distinction, strategy, interpretation and generation are higher-order thinking skills. Since problem solving taxonomy is recommended for use in the technological field [50, 51], we used it in the present study.

THE LEARNING UNIT

The proposed learning unit, based on computer animation, is the core of the course "Introduction to Electronics". According to the learning objectives, at the completion of the course students will be able to solve problems (routine-interpretation levels) in the following areas: the principle of operation of the BJT (NPN-type), BJT modes of operation (active, saturation and cut-off) and operating point analysis[2]. The solution of these problems is mainly based on qualitative analysis. This introductory course prepares students for further courses dealing with advanced electronic devices based on the BJT, such as current sources and amplifiers.

Animations on the subject of the BJT currently available[3] are not suitable for practical engineers because they are either too simplistic, or alternatively, because they are at a university level, which

2 An NPN bipolar junction transistor is built of a "sandwich" of three pieces of semiconductor: N-type semiconductor, P-type semiconductor, and N-type semiconductor. The transistor consists of three parts: "emitter", "base" and "collector", where each part is found in a different piece. Depending on the external voltage on the transistor, a number of modes of operation can be defined for the BJT: "active", "saturation" and "cut-off".

3 For example: http://www.learnabout-electronics.org/bipolar_junction_transistors_05.php

requires advanced mathematical and physical knowledge that is not in possession of the practical engineering students. We, therefore, developed a new learning unit based on computer animation that was tailored to the practical engineering students' background. Thus, contrary to existing animations that use advanced physical concepts, such as the Fermi level, and are based on quantitative analysis, the animation we developed refrains from the use of advanced terms and is mainly based on qualitative analysis without the need to solve differential equations. It should be noted that the decision to develop new animation was made following a thorough search of databases and consulting with senior faculty members in departments of electrical and electronics engineering in Israel. Development of the animation, by a graduate student in engineering education who used Microsoft PowerPoint, took 100 hours.

The new unit is based on the Sedra and Smith textbook [52] and qualitatively describes the processes occurring in the transistor in its three modes of operation: active, saturation and cut-off. The screenshots in Fig. 1 and Fig. 2 describe a BJT (NPN-type) in its active mode. The animation was designed in light of the principles of [6, 14] mentioned earlier. In particular, we carefully incorporated written text in spatial proximity to the animation (spatial contiguity principle), and avoided the use of excess items distracting the learner from the point (coherence principle). Additionally, we used arrows as visuospatial cues [27]. The lesson dealing with the BJT was based on the use of animation without supplemental material. As the animation is non-interactive and does not include its own narration, it was presented to the class by the

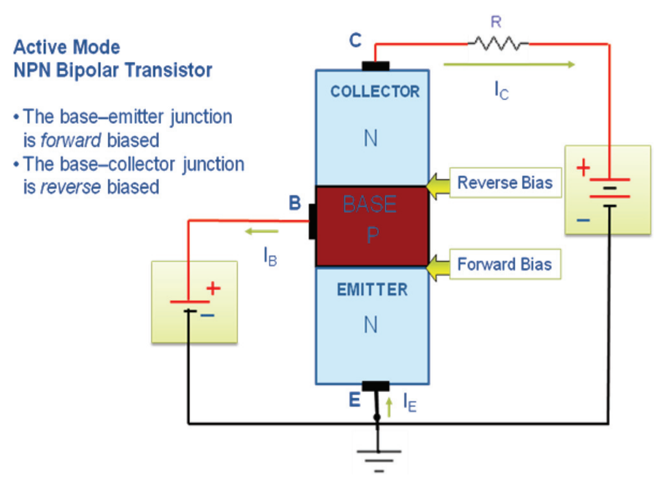

Figure 1. Screenshot describing an NPN bipolar junction transistor in active mode.

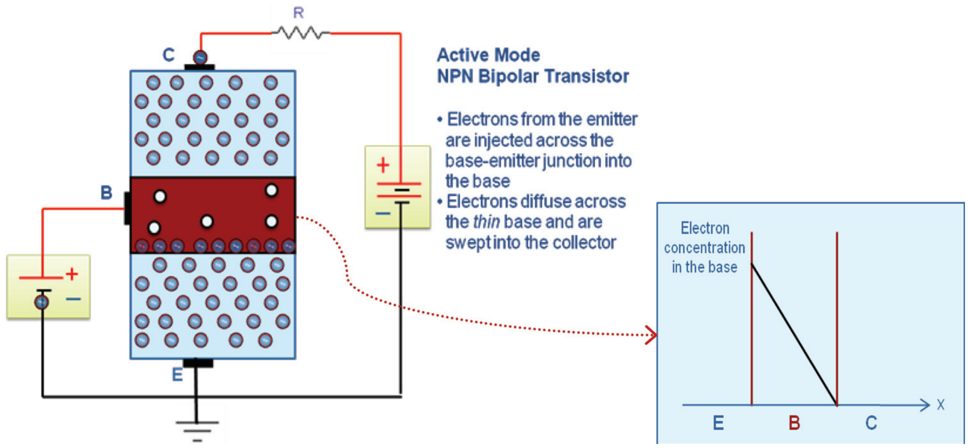

Figure 2. Screenshot describing the processes electrons (marked as solid balls) undergo in the transistor in active mode. The holes are marked as hollow balls.

teacher. Verbal explanations were provided by the teacher in a temporary proximity to the animation (temporal contiguity principle). The teacher also called the students' attention to key details in the animation and specified its limitations in order to avoid misconceptions. For example, the teacher noted that the animation is not to scale. She also emphasized that the movement of electrons is accompanied by many more collisions than depicted in animation. These explanations were given in an informal language, using the first and second person (personalization principle).

In addition, we developed a parallel learning unit, with identical number of hours, engaged in the same contents as the learning unit described above, only it does not include computer animation but uses static diagrams drawn on the blackboard. The research compared the academic achievements and attitudes of students who studied the different units. It should be noted that the diagrams drawn on the board by the teacher represented key points of the processes occurring in the transistor. They were as similar as possible to screenshots, in both dimensions and content. The major difference was that the former were drawn by hand and therefore straight lines were not perfect. Additionally, effort was made to ensure the teacher's explanations to the control group, where the structure and principle of operation of the BJT were taught using static diagrams, would be as close as possible to the text accompanying the animation and explanations provided to the experimental group where students studied these subjects through animation. This was carried out by prior preparation of these explanations before the lesson and adhering to them in the course of the lesson.

RESEARCH QUESTIONS

The objective of this study was to characterize animation based learning on the subject of the bipolar junction transistor. The following research questions were derived from the research objective:

- What are the academic achievements of students studying the subject of the BJT through animation, compared to those of their peers who studied the subject using static diagrams?
- What are the students' attitudes towards electronics in general, and animation based learning on the subject of the BJT in particular?

METHODOLOGY

Participants

The research population comprised of 41 students who studied towards a practical engineering degree in electronics at a leading college in Israel. The students were randomly assigned into two groups: an experimental group of 21 students – where the structure and principle of operation of the BJT were taught through animation presented by the teacher and a control group of 20 students – where students studied these subjects using static diagrams drawn on the blackboard by the teacher.

Methods

The research was a mixed method research, combining data collection using quantitative instruments alongside qualitative ones [53]. The quantitative part examined the students' academic achievements and attitudes through achievement tests and Likert-like attitude questionnaires, respectively. At the qualitative part, data were collected through interviews in order to thoroughly understand the students' attitudes.

For the quantitative part of the study we chose the pretest-posttest control group design, offered by Campbell and Stanley [54]. Members of each group were examined in an identical preliminary achievement test on the subject of the diode which is a prerequisite subject to BJT. It should be noted that the subject of the diode was taught using static drawings. Later, the experimental group learned the new unit on the structure and principle of operation of the BJT using animation presented by the teacher, while the control group learned the same contents, for the same number of hours and by the same teacher, using static diagrams drawn on the blackboard. At the end of learning, the two groups were examined in an identical final achievement test on the subject of the

BJT. In addition, the same experimental design was used to check the students' attitudes towards electronics. Thus, members of each group completed a Likert-like attitudes questionnaire before studying the subject of the transistor and after it.

At the end of the learning, four semi-structured interviews with students in the experimental group were carried out. The interviews intended to supplement the information obtained by the quantitative instruments, focused on the students' attitudes towards animation based learning and tried to trace the factors leading to the students' achievements. The interview questions are provided in Appendix A. Students' comments underwent content analysis and were classified into categories. The categories include only findings found in at least three interviews. The tri-component attitude model (ABC model) served as a theoretical framework for the qualitative analysis.

Instruments

Each of the two achievement tests was validated by two experts from the field of education in electrical engineering. To ensure objectivity, each test was graded laterally[4] by two independent reviewers, using a rubric. The tests, which did not include the name of the examinee but rather only his identification number, were graded in random order to mix the experimental group students and the control group students. The preliminary achievement test, on the subject of the diode, included 8 problems, out of which 3 whose solution was classified by two experts as requiring the use of higher-order thinking skills (strategy and interpretation) according to the problem solving taxonomy discussed above. The inter-rater reliability was 0.97. The final achievement test, on the subject of the BJT, included 9 problems, out of which 4 whose solution was classified by two experts as requiring the use of strategy and interpretation skills. The inter-rater reliability was 0.99. Students' achievements were analyzed in three ways: total achievement, based on the total test score, higher-order thinking level, based on the score of the problems classified as requiring higher-order thinking skills, and lower-order thinking level, based on the score of the rest of the problems. A sample of the problems is given in Appendix B.

Each of the two attitude questionnaires, the preliminary and final ones, was validated by two experts from the field of education in electrical engineering. The preliminary attitude questionnaire, completed prior to learning the subject of the BJT, included 10 statements dealing with enjoyment and interest associated with learning electronics and the existence of a sense of competence to successfully deal with problems on the subject of the diode. For example, "The material being studied at the course is interesting" and "I am capable of explaining how a diode works". Cronbach's

4 In a lateral grading, the first question is graded in each of the tests. Later, the second question is graded in each of the tests, and so on until the last one.

alpha was 0.77. The final attitude questionnaire, completed after learning the subject of the BJT, included 10 statements dealing with enjoyment and interest associated with learning electronics and the existence of a sense of competence to successfully deal with problems on the subject of the transistor. Cronbach's alpha was 0.83.

FINDINGS

First, we introduce the findings relating to the academic achievements of the students. Then, we describe the findings concerning the students' attitudes towards electronics in general, and animation based learning on the subject of the BJT in particular. For the quantitative analysis, we used independent t tests and the Mann-Whitney test to compare students' achievements and attitudes, respectively.

Academic Achievements

Table 1 shows the total score (out of 100 points) of the achievement tests (mean M and standard deviation SD) obtained in each group, and the corresponding p-values obtained from performing t tests. There was no significant difference between the experimental group and the control group before learning the subject of the BJT, but afterwards – the mean total score of the experimental group was significantly higher than that of the control group. The score (out of 100 points) of the problems whose solution involves higher-order thinking skills (strategy and interpretation) and lower-order thinking skills (routine and diagnosis) is presented in Tables 2 and 3, respectively. Again, there was no significant difference between the experimental group and the control group before learning the subject of the transistor, but afterwards – the average score of the experimental group was significantly higher than that of the control group. The overall effect size (Cohen's d) was 1.05. The effect size relating to higher-order thinking skills (1.24) was considerably higher than the effect size relating to lower-order thinking skills (0.74).

		Pretest				Posttest			
Group	N	M	SD	t	p	M	SD	t	p
Experimental	21	67.95	23.54	0.31	n.s.	78.24	11.13	3.37	<0.001
Control	20	65.80	20.30			66.15	11.86		

Table 1. Achievement tests: Total scores and p-values.

		Pretest				Posttest			
Group	N	M	SD	t	p	M	SD	t	p
Experimental	21	64.57	30.07	0.12	n.s.	82.23	10.91	3.97	<0.0005
Control	20	65.59	22.86			68.65	11.00		

Table 2. Achievement tests: Higher-order thinking skills scores and p-values.

Attitudes

Findings concerning the students' attitudes towards electronics in general, and animation based learning on the subject of the BJT in particular were obtained from attitude questionnaires and interviews analysis. Table 4 shows the index median (m) and the corresponding p-values obtained from performing the Mann - Whitney test[5]. Index values range between 20 and 100 points. There was no significant difference between the experimental group and the control group before learning the subject of the BJT, but afterwards – the median of the experimental group was significantly higher than that of the control group. These results indicate that the experimental group students' attitudes towards electronics are significantly more positive than those of their counterparts in the control group.

A content analysis of the interviews, based on the tri-component attitude model, yielded the categories shown in Table 5.

DISCUSSION AND CONCLUSIONS

This article presented the results of an evaluation research, which examined animation based learning characteristics of practical electronics engineering students in a leading Israeli college. The evaluated learning unit deals with the structure and principle of operation of the BJT, a subject that forms the basis of electronics engineering studies. The unit was developed by the researchers

		Pretest				Posttest			
Group	N	M	SD	t	p	M	SD	t	p
Experimental	21	69.52	24.41	0.51	n.s.	75.64	14.48	2.38	<0.05
Control	20	65.88	23.30			64.30	15.97		

Table 3. Achievement tests: Lower-order thinking skills scores and p-values.

5 A normal distribution of the index cannot be assumed; therefore we performed a non-parametric test.

<table>
<tr><th rowspan="2">Group</th><th rowspan="2">N</th><th colspan="2">Pretest</th><th colspan="2">Posttest</th></tr>
<tr><th>m</th><th>p</th><th>m</th><th>p</th></tr>
<tr><td>Experimental</td><td>21</td><td>71</td><td rowspan="2">n.s.</td><td>82</td><td rowspan="2"><0.01</td></tr>
<tr><td>Control</td><td>20</td><td>67</td><td>62</td></tr>
</table>

Table 4. Attitude questionnaires: Index median and p-values.

in response to the difficulty faced by teachers when they teach this complex subject. The difficulty, also described by [3], derives from lack of adequate mathematical and physical background among the students [4], characterized by a relatively low achievement level [1]. The animation, which was tailored to the students' background, focuses on a *qualitative* description of dynamic processes

<table>
<tr><th>Category</th><th>Sub category</th><th>Example</th><th>Interpretation</th></tr>
<tr><td rowspan="3">Cognitive and meta-cognitive</td><td>Reducing the cognitive load</td><td rowspan="2">I think it [the animation] is very important . . . I'd rather learn all the other topics and subjects with animations . . . It actually shows us how it works . . . Unlike the explanations from the blackboard [on the subject of the diode] ". . . it [an electron] goes there . . . and that one [other electron] is going in this direction". When explained in that way . . . I personally lose the overall vision . . .</td><td>Animation reduces the cognitive load imposed on the learner – a load resulting from the need to build a dynamic picture, necessary to understand the processes occurring in the transistor</td></tr>
<tr><td>Contributing to organization of knowledge</td><td>Animation contributes to organization of knowledge</td></tr>
<tr><td>Assisting metacognition</td><td>Once the teacher explains something with electrons . . . I can imagine . . . When I imagine it could be correct or incorrect . . . The animation actually gives me something definitive . . . that what I imagined is right or wrong . . .</td><td>Animation provides a 'definitive' comparison to students' own interpretation</td></tr>
<tr><td rowspan="2">Affective</td><td>Creating interest in a direct channel</td><td>In my opinion, the use of animation is a good method . . . very interesting . . .</td><td>The animation itself creates interest among the students</td></tr>
<tr><td>Creating interest in an indirect channel</td><td>If I understand something then I'm interested in the material . . . That's what happened [after seeing the animation] . . .</td><td>The use of animation improves understanding and this improvement is what makes the student be interested in the material</td></tr>
<tr><td rowspan="2">Behavioral</td><td>The student's delving</td><td>If I understand something then it makes me solve more and more exercises... That is what happened to me on the subject of the BJT...</td><td>Following the use of animation the student began to delve deeper into the subject of study</td></tr>
<tr><td>Attracting the student's attention</td><td>Student: "In this lesson [on the subject of the BJT] I did not disrupt and I was focused during the entire lesson…"
Researcher: "Why, what was the reason?"
Student: "I think the animation gave me motivation to continue to look at it... It is more interesting to learn with animations..."</td><td>Animation attracts the attention of the students and reduces disruptions during class</td></tr>
</table>

Table 5. Content analysis of the interviews.

occurring in the transistor in its different modes of operation, and designed in light of the principles of Mayer and Moreno [6] and Kali and Linn [14].

The research results indicate a significant gap between the academic achievements of students studying the subject of the BJT through animation and the achievements of their peers who studied it using static diagrams. The gap in favor of the first can be partially attributed to cognitive factors, such as the reduction of the cognitive load imposed on the student – a load resulting from the need to build a dynamic picture necessary to understand the processes occurring in the transistor. Another contribution can be attributed to motivation due to the students' interest in the animation. As mentioned earlier, there is an ongoing debate in literature, without definitive conclusions so far [17, 23], between the supporters of the static hypothesis [19] and the dynamic one [21]. The present research findings support, therefore, the argument of the dynamic media hypothesis, according to which the use of computer animation promotes learning better compared to the traditional teaching methods.

In addition, our research shows that students who studied about the BJT through animation express significantly more positive attitudes towards electronics than their peers. Thus, students studying on the subject of the BJT through animation feel more interest and enjoyment in electronics classes than their peers who studied using static diagrams. Moreover, their sense of competence to successfully deal with problems in the field is higher compared to their colleagues. A qualitative study of students' attitude towards animation based learning shows that the attitude comprises cognitive and meta-cognitive, affective and behavioral components. According to the findings, animation contributes to organization of knowledge and self reflection of the learning process. These contributions improve the students' cognitive and meta-cognitive abilities [55], expressed in their achievements. Additionally, animation reduces the cognitive load imposed on the student, as discussed above in light of the dynamic media hypothesis. An analysis of the findings concerning the affective component indicated that animation creates interest in the study material in two channels: direct and indirect. In the direct channel, interest stems from the animation itself, whereas in the indirect channel, interest is caused by the improvement in student understanding. These findings can be explained by the self-determination theory [56, 57], according to which, improved understanding contributes to satisfying the need for competence and thus enhances the intrinsic motivation, whose most prominent characteristic is the display of interest. According to Deci et al. [58], the intrinsic motivation has a central role in learning involving higher-order thinking skills. This argument is consistent with the research findings indicating a significant improvement in higher-order thinking skills score of the experimental group members compared to the control group members, as well as the sense of interest and enjoyment in the learning process among the former. This sense of interest also relates to the dynamic media hypothesis, which states that animation creates interest leading to the learner's motivation to invest more effort in understanding the learned material [20]. The last component of the attitude, the behavioral component, indicates that the experimental group members demonstrated great interest in learning and the lesson was conducted without any disruptions.

As noted, the findings of the present research indicate a gap in favor of students who studied through animation both in academic achievements and the extent of interest shown in the subject matter. These results are consistent with the findings of [45] who developed, for physics students, a courseware on semiconductor devices, but are not fully in accord with the findings of [44]. The authors of [44] developed animations for electrical engineering students, focusing on the processes of drift and diffusion in semiconductors, and found a remarkable improvement in interest students had shown, but not in their level of understanding. In this comparison it is important to remember that the research population of the above mentioned studies included students studying towards a first degree in engineering or physical sciences. This population differs substantially from practical engineering students characterized, as mentioned, by a relatively low level of achievement and in that they do not aspire for academic studies [1].

This research has several limitations. It was based on a relatively small sample, and the conclusion validity obtained from the analysis of the Likert-like attitude questionnaire is not high due to the low power of the non-parametric test we used. The small sample precluded active learning in groups, within the experimental group, in the TEAL[6] Project format, which is characterized by multimedia based learning that includes problem solving and discussions between peers in groups [5]. We believe that if it were possible, then the gap found in the present research between the academic achievements and attitudes of the experimental group and those of the control group was even larger. Additionally, the findings may have been influenced by the novelty of animations to the students, i.e., the novelty effect [59] or the interest they found in this technological means which is different from their regular learning environment. It is also possible that a bias in favor of the experimental group unconsciously affected the teacher and her expectations of the students [60], but these effects alone cannot explain the large gap obtained.

Despite these limitations the study has significant strengths: the students participating in the study were randomly assigned into experimental and control groups and the two groups learned the same contents for an identical number of hours with the same teacher, who took care that the only difference between the two groups will be around the method of instruction (animation or, alternatively, static diagrams). This reinforces the internal validity of the research findings. Another advantage is that for the purpose of answering the research question dealing with student attitudes toward animation based learning, we did not settle for the above attitude questionnaire but also used qualitative instruments in order to enhance the trustworthiness of the findings.

6 TEAL = Technology-Enabled Active Learning.

The theoretical contribution of the research lies in characterizing animation based learning on the subject of the BJT, both in the cognitive and affective aspects, among practical electronics engineering students. This contribution is further reinforced by the fact that understanding the BJT principle of operation forms the basis for electronic engineering studies. The practical importance of the research lies in the development of a new learning unit based on computer animation that was *tailored* to the practical engineering students' background and qualitatively describes the processes occurring in the BJT. Such a unit was developed, to the best of our knowledge, for the first time. The practical contribution may be expressed in the implications of the research findings on curriculum design for practical engineers in general and practical electronics engineers in particular. We believe these contributions are significant given the scarce of research literature dealing with practical engineers. In light of the research results, we recommend that our colleagues include animations, developed with an eye toward the students' background, when teaching the operation principles of electronic devices such as the bipolar junction transistor.

This research may form the basis for further studies examining whether the gap found in the present study, between the experimental group scores and the control group scores, will be maintained in advanced electronics courses learned by the students who participated in the research.

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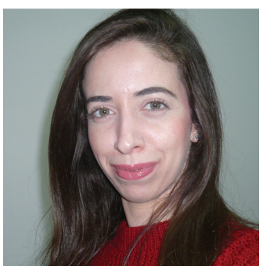
AUTHORS

Aharon Gero holds a B.A. in physics, a B.Sc. in electrical engineering, an M.Sc. 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.



Wishah Zoabi received a B.Sc. in Technology and Science Education in 2008 and an M.Sc. in Technology and Science Education in 2012, from the Technion – Israel Institute of Technology. She is a lecturer at the Department of Electronics and Electrical Engineering of Ort Braude College, Israel. Her research focuses on animation-based learning of electronic devices for practical engineering students.

Nissim Sabag is a senior lecturer at the Department of Electronics and Electrical Engineering of Ort Braude College, Israel. His academic activity comprises electrical engineering as well as engineering education. He holds a B.Sc. in electrical engineering (1982), and a B.Sc. (1995), an M.Sc. (1998), and a Ph.D. (2002) in Technology and Science Education, all from the Technion – Israel Institute of Technology.

APPENDIX A: INTERVIEW QUESTIONS

Below are the interview questions discussed in the methodology section.

- Describe a subject of the course you relate to.
  Explain why you relate to it.
- Are you capable of explaining the operation principle of the BJT?
  If so, explain it and specify what was in the lesson that helped you understand the above principle.
- What do you think of the use of animation in the course?
- Did the use of animation affect your understanding?
  If so, in what subjects and how?
- Did the use of animation affect your interest in electronics?
  Describe how.

APPENDIX B: ACHIEVEMENT TESTS

Listed below are the topics included in the preliminary achievement test and final achievement test, discussed in the methodology section. The tests were devised to check to what extent students developed thinking skills on routine-interpretation levels with regard to the diode (current-voltage characteristics and operating point analysis) and the BJT (principle of operation and operating point analysis). Also attached is a sample of problems taken from these tests, while indicating the level of each problem according to the problem solving taxonomy, described in the theory section.

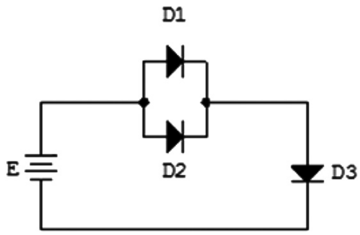
1. Preliminary achievement test

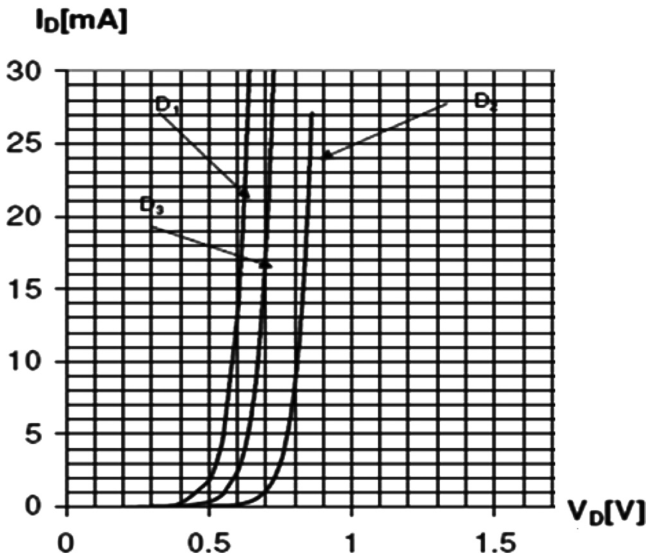
a) Subjects

- Diode modeling
- Current - voltage characteristics
- Operating point analysis

b) Sample problem

(Interpretation) Consider the following circuit. The current of D_1 is 16mA. Using the current-voltage characteristics, determine the voltage across D_3.





2. Final achievement test

a) Subjects

- Principle of operation of the BJT in the following modes:
  - Active
  - Saturation
  - Cut-off
- Operating point analysis

b) Sample problem

(Strategy) Explain why the following relationship exists between the currents in an NPN transistor in active mode.

$$I_E > I_C \gg I_B$$