Chapter 3

Using the Knowledge of Biomechanics in Teaching Aikido

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Additional information is available at the end of the chapter

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1. Introduction

The title of the chapter refers to the research work that the author has been doing into the application of the knowledge of biomechanics in the methodology of teaching motor activities in sports disciplines involving a complex rotational movement of a human body. The author, who previously worked as a PE and physics teacher in a secondary school and an aikido instructor, now teaches biomechanics at university. Basing on his earlier work results, the author found out that some notions in mechanics are better acquired if explained using sports performance examples. According to the author, motor activities of a particular technique practised in PE and aikido classes were mastered best if their dynamics were explained to students using the principles of physics. This method also accelerated the process of understanding the rules of mechanics by the students executing a particular technique. The feelings of the students were similar - in the questionnaire made with 273 randomly chosen [1,2] secondary grammar and technical school pupils, 85% of the subjects supported explaining the rules of mechanics using sports performance examples, whereas 76% of them also supported the method of explaining techniques of the performance of certain exercises involving the rules of physics. The present chapter illustrates the experiments that verified the above-mentioned findings. The tests mainly showed the use of the knowledge of biomechanics in teaching aikido. Some of the groups of adolescents were involved in the experiments at a time interval. The first experiments carried out also checked if the effect of the knowledge of biomechanics on a shot put was increased range. The objectives of the paper are: 1. Presenting the knowledge of the biomechanics of aikido techniques. 2. Verifying whether teaching mechanics by explaining its rules using examples from aikido and various sports disciplines increases the efficiency of teaching. 3. Checking how the knowledge of biomechanics related to the rules of mechanics used in aikido techniques and shot put can improve their performance correctness. 4. Checking how a method of teaching aikido can affect the efficiency of learning aikido techniques by children.

2. Biomechanics of aikido techniques

2.1. The principles of mechanics used for executing aikido techniques

The term "aikido technique" must be precisely defined. There are multiple definitions of "sports technique" in professional literature. Bober [3] in his analysis of definitions of sports technique follows Zatsiorsky [4] who thinks that a sports technique is a term which can be described rather than defined. In the author's opinion [2], the term aikido technique refers to a way of neutralizing a specific attack and simultaneous execution of a specific motor task. Neutralizing can be made [5] by (1) locking, (2) throwing or (3) a combination of both. The neutralizing technique differs with regard to the type of attack. Aikido characteristically has a great number of techniques depending on the combination of the means of neutralization and the type of attack. Aikido is a martial art of a defensive character using the power of the attacker. In the self-defence process the following rules are applied [2,6,7]: "give in to win", "turn around if you are pushed", "move forward if you are pulled". In principle, aikido techniques should be elaborated in such a way as to make it possible for even a physically weaker person to execute them against a stronger person [8]. Simplifying the mechanical analysis, this can be confirmed by the principles of mechanics [6]. Aikido is practised mainly as a form of self-defence and it most frequently lacks sports competition. There is a clear division onto the defender executing certain techniques and the attacker against whom this technique is performed. The rules mentioned lead to a conclusion that the defender tries not to stop the attacker's move, especially with his smaller power and weight when it is impossible. If the attacker pulls with a certain force F_A (Fig.1a), then with a smaller strength of the defender F_B the result of these forces is directed at the attacker, a good solution is a sudden change of the defender's force direction into the one consistent with the force of the attacker. The resultant force being a sum of the vector values can surprise the attacker and make him lose balance. If, on the other hand, the attacker pushes with a greater force than the defender can resist, the resultant force will also have the direction of the attacker's force. In this case, a good solution would be to step out of the line of the attack.

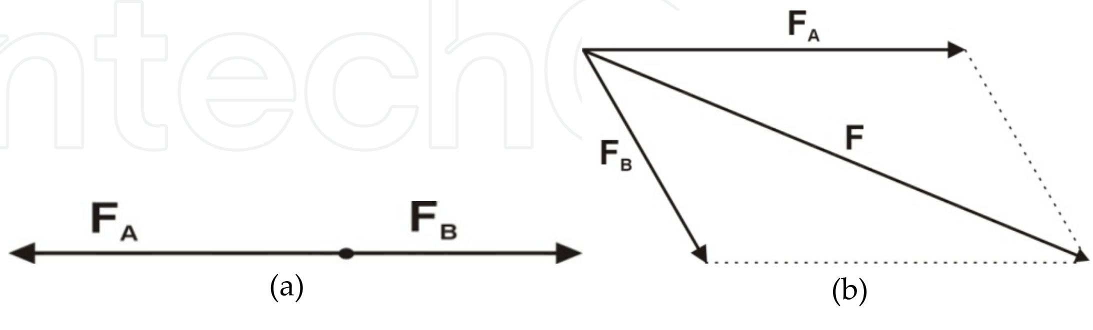

Figure 1. Generating the resultant force when the attacker (published in [6])
a) pulls the defender
b) pushes the defender

The resultant force of two convergent vectors that is then produced makes it possible to change the direction of the attacker's move (Fig.1b) The defender, by stepping out of the line of the attack changes the direction of the attacker's motion from rectilinear to curvilinear. He tries to move on the smallest possible curve. If the attacker moves in the same direction as the defender, then he additionally gains centrifugal force. If the practitioners' weights are combined by, for example, doing a grip by only one of them, then the second principle of dynamics is present here.

$$\varepsilon = \frac{M}{I} \tag{1}$$

The defender, along with decreasing the curvilinear motion radius, is decreasing the moment of inertia I of the practitioners. He tries to move in such a way as to ensure that at the end of performing the technique, the axis of motion rotation is possibly the closest to his body. When executing a certain technique, aikido practitioners are acting with certain forces, and since it is a curvilinear movement, a resultant moment of force M is produced. This moment of force, with decreasing the moment of inertia of the subjects, results in an increase in the angular acceleration ε in this motion (1). However, this analysis is of rather an approximate character. A human body is not a single solid and in a close study a biomechanical segment model of human body structure should be assumed. It is advised to apply Steiner's theorem (2) for determining the moment of inertia.

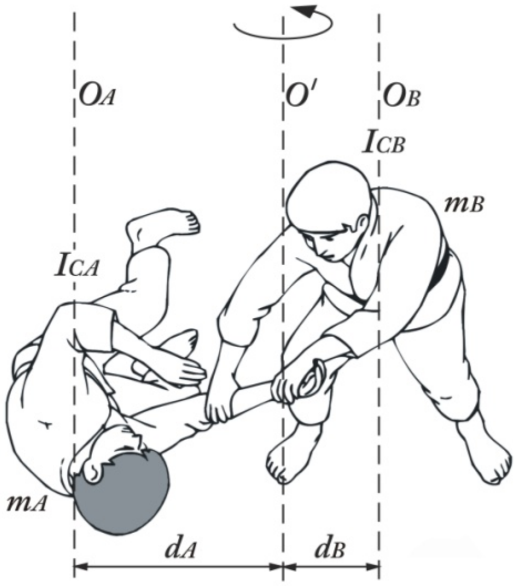

Figure 2. Analysis of distribution of the practitioners' masses around the common axis of rotation O' in the final stage of the technique

$$\begin{gathered} I' = I_c + md^2 \\ I' = I_A' + I_B' \quad I_A' = I_{CA} + m_A d_A^2 \quad I_B' = I_{CB} + m_B d_B^2 \end{gathered} \tag{2}$$

The moment of inertia I′ is a sum of the moments of inertia of the subjects, namely the attacker I_A' and the defender I_B'. For this purpose, their central moments of inertia I_{CA} and I_{CB}, as well as the distances d_A and d_B from their centres of mass m_A and m_B (Fig. 2), must be determined. When the radius on which the attacker is moving decreases, the moment of inertia of the position of the practitioners' bodies gets smaller and their angular velocity rises. If we neglect the motion resistance, we can talk about the principle of the conservation of the moment of momentum

$$I\omega = \text{const} \tag{3}$$

The subjects behave similarly to figure skaters when performing a pirouette. In this figure they move their lower limbs close to the axis of rotation and by doing this they increase their angular velocity ω. In some moment of the motion, the centre of mass of the defender should be at the closest possible distance from the axis of rotation of the performers' bodies' arrangement. His hands should be as close to this axis as possible. This leads to a decrease in the moment of inertia of the performers and to an increase in the value of the centrifugal force F acting on the attacker.

$$F = \frac{mV^2}{r} \tag{4}$$

As the formula (4) shows, the centrifugal force gets bigger when the velocity the attacker attacks with goes up, his weight increases and the radius he follows gets smaller. The behaviour of the attacker can be compared with the behaviour of a car on a road bend. The sharper the bend and the smaller the radius r, the bigger the car speed V and the bigger force acting on the car, increasing the risk of falling off the track. The behaviour of the defender resembles the motion of a spinning top (Fig. 3). The external force acting on the spinner cannot disturb its rotational movement. The defender makes a move causing the attacker and not the defender to gain the centrifugal force. Therefore, he performs stepping out of the line of the attack in such a way so as the whole motion is done around the axis of rotation going most desirably through his body.

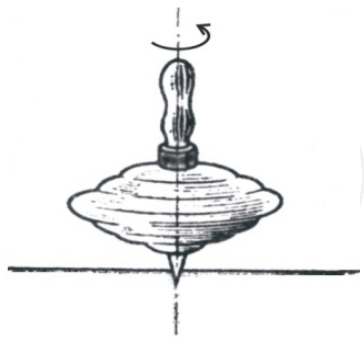

Figure 3. Spinning top (published in [6])

The centrifugal force may allow neutralizing the attack. However, it is usually too small to knock the attacker over. In order to do a throw, the defender uses his weight, which when adequately transferred may exceed the centrifugal force gained by the attacker [6]. Therefore, in a great number of techniques, the defender suddenly lowers his centre of mass in order to increase the technique dynamics. In the final stage of the throw, provided the attacker's body is inclined enough, in order not to meet his unexpected counter-punch, the defender is even likely to do a one leg jump. When performed correctly it facilitates the shift of the defender's weight down. Then all his P=mg is used in the technique. Most frequently the force enabling an aikido throw is a result of the centrifugal force of the attacker and the weight of the defender (Fig. 4). A good example illustrating the conduct of the defender would be a spinning top that apart from a rotational motion would do an up movement, such as jumps. An approximate formula for a resultant force producing a throw can be determined as follows:

$$F = \sqrt{\left(\frac{m_2 V^2}{r} + \left(m_1 g\right)^2\right)} \quad (5)$$

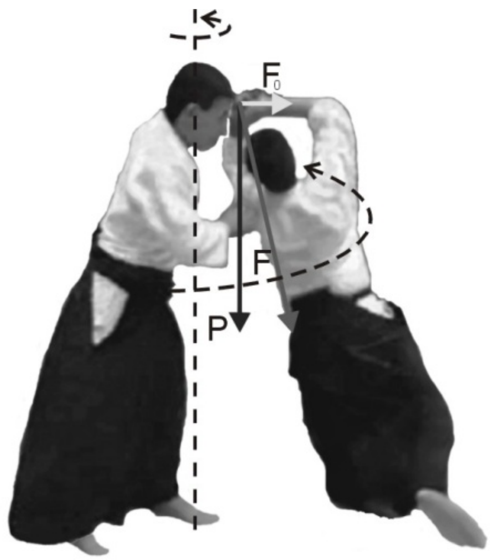

Figure 4. Resultant force acting on the attacker in the final stage of the technique (published in [6])
m_1 – the defender's mass
m_2 – the attacker's mass

The figure does not show all the vectors of the force, which can be obtained by means of, for example, pelvis turns, characteristic for aikido performed by the defender along with the body turns around in a horizontal plane, or by means of a force coming from the use of particular muscles of the attacker. Many authors explain the dynamics of the defence techniques (in martial arts) quoting the principles of biomechanics [6-11]. Of special interest here are the lectures of Jigoro Kano explicating the "give in to win" principle. The father of judo was familiar with the biomechanical aspects of judo. The interplay of centrifugal and centripetal forces or movements resembling a spinning top involved in the execution of aikido techniques was understood by the son of the aikido founder Kishomaru Ueshiba [12]. Koichi Tohei [13], the only one who was awarded by the founder of aikido when he was still alive with the 10th Dan, claimed that the secret of Morihei Ueschiba was his ability to relax when executing the techniques which was also due to a low position of the centre of mass. However, it is not a complete loosening of muscles, but rather straining the muscles which, for example, causes a child to have such a power that another person cannot snatch the child's favourite toy out of his hands. This ability of relaxing or loosening referred to above, is related to the concept of "ki". The idea of "ki" has rather a wide meaning in the Japanese culture and it is difficult to translate it into a European meaning. Generally, it is understood as life energy possessed by every man. However, an explicit explanation of "ki" in terms of mechanics is at the current level of research limited and thus goes beyond the subject matter of this presentation. The breathing techniques generally applied in some aikido schools understood as developing "ki" make it possible to master the ability to relax/loosen when doing a throw. In terms of throw dynamics in aikido it gives a greater possibility to shift the force coming from the weight of the defender P=mg.

3. Biomechanical analysis of aikido techniques executed by the disabled

It is obvious that in combat sports competition between a disabled person, for example, missing one limb, and a fit person is practically impossible. Lack of full power in one of the limbs gives a significantly smaller attack power and its potentials. In the case of a necessary self-defence, a disabled person, by using the power of the attacker, has a chance to execute some aikido techniques. Below, the author gives a mechanical analysis of some aikido techniques performed by disabled persons [14]. Together with the pictures you will find figures presenting force vectors in two planes. It would be more precise to show the vectors acting in a 3D plane, but this would not be readable in this paper. For convenience, Fig. 5 illustrates vectors in a horizontal plane and in Fig. 6 they are shown in a vertical plane.

3.1. Execution of aikido techniques by people with a dysfunction of an upper limb

The technique (Fig. 5) illustrates a defence against an attack made by hand in a circle throw at the head level. The defender steps out of the line of the attack, grasping the attacker's hand. The attacker works with force F_A, the defender with force F_B, their vector sum gives vector F (Fig. 5). In the next stage of the technique under analysis, the defender lowers his centre of mass. In this way he supplements the force configuration with force G that comes mainly from the weight of the defender (Fig. 6). This force is of a great importance in the dynamics of aikido techniques, provided it is transferred at the right moment of the technique [6].

Figure 5. Defence against an arm attack following a circle at the head level – analysis of forces in a horizontal plane (published in [14])

In the vertical plane, force F and the force G give a resultant F_W. When executing a technique the defender does a turn around in order to shorten the radius followed by the attacker. The attacker is acted on with the moment of force equal to the product of the *Fw* resultant and the radius on which the attacker is moving.

The moment of the force produced causes the attacker to lean forward and lose his balance.

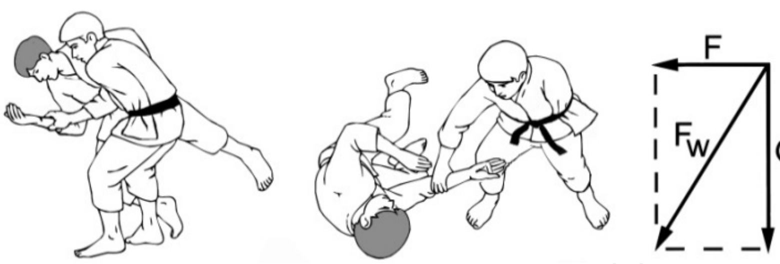

Figure 6. Defence against an arm attack following a circle at the head level – analysis of forces in a vertical plane (published in [14])

The above-mentioned aikido technique can be performed by a disabled person using only one upper limb. Force G is the most important as far as the dynamics of this technique execution is concerned. For applying this force, only one upper limb is needed, because only one point of the force application is enough. The application point of force G is supposed to be like "the eye of a cyclone". It is a central place where movement is the smallest. Force F_b changes the direction of the attacker's move (its value does not have to be big). Only one hand is needed for this change of direction, whereas the other can, for example, shield the body. With adequate speed of the defender, this technique can be executed with one hand neglecting shielding of the body. As previously mentioned, the movement of the defender in aikido often resembles the motion of a spinning top [Fig. 3], which apart from rotating also executes an upward movement. At the end of the technique the arms are in most cases placed close to the axis of the body rotation.

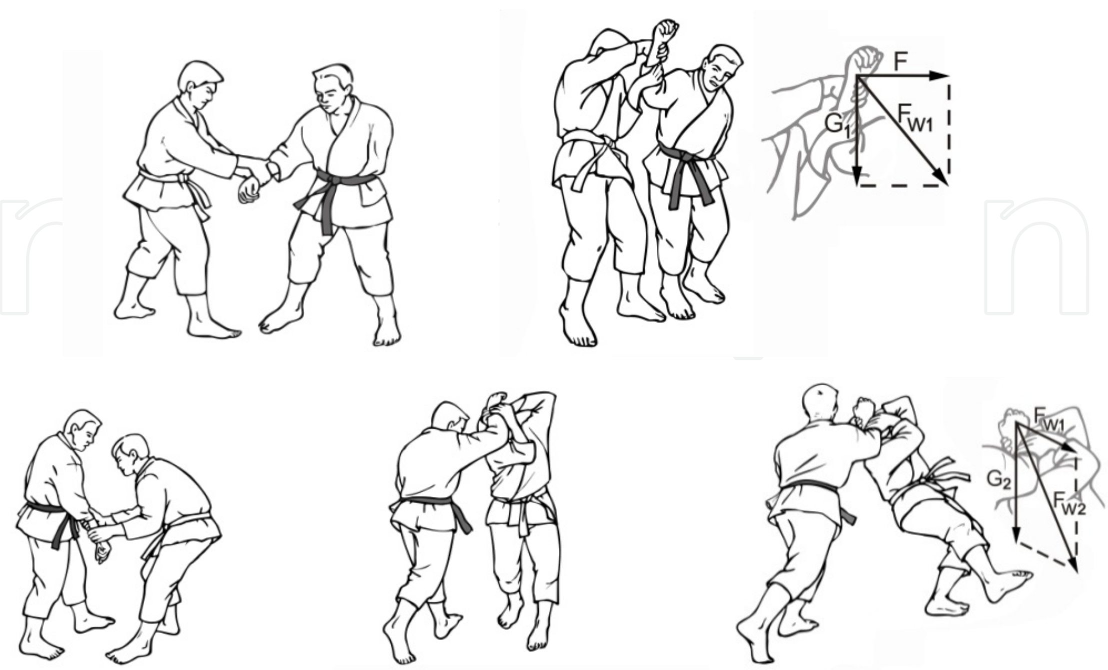

Figure 7. A form of a defence - grasping the attacker's arm with both hands (published in [14])

Aikido comprises many techniques using a movement of only one upper limb. These techniques are executed following the same principles of mechanics as shown in Figures 5 and 6. There are many possibilities of mechanical motion versions, thus, their description can be too much expanded upon. Figure 7 presents an example of a more complex technique. The attacker grasps the defender's hand with his both hands. As a result of stepping out of the line of the attack and shifting the body mass down along with the movement of the arm, the first resultant force F_{w1} is obtained. This force, as in Figure 7, is a result of forces F and G_1 coming from the mass of the defender. In terms of the technique, force F_{w1} is used mainly for a correct leaning of the attacker and for giving speed. Then, after moving the centre of mass up and down again, along with the movement of the hand, force G_2 is produced that comes mainly from the mass of the defender. Roughly speaking, the composition of the forces G_2 and F_{w1} gives a resultant F_{w2} causing the attacker's fall. It is quite easy to select from the aikido repertoire the techniques for which only one upper limb is used. Thus, these techniques can be used by disabled persons who have only one efficient arm.

3.2. Aikido techniques for people with a dysfunction of a lower limb

Some aikido techniques involve the *hanmi handachi waza* position for their execution, with the attacker in a standing position and the defender in a kneeling position. This practice dates back to ancient Japanese rituals, where people used to have meals and relax in kneeling positions [5]. A samurai in this position was prepared to defend himself against a sudden attack of his opponent by means of certain defence techniques that he had mastered. Many aikido masters have claimed that executing aikido techniques in a kneeling position particularly influenced their execution in a standing position. Aikido techniques performed in a kneeling position can be executed by people with certain dysfunctions in lower limbs, for example, as a result of limb amputation below the knee. It is crucial that the defender maintains the point of support on his knees. Figure 8 illustrates an example of a technique executed by a kneeling defender. The technique presented is a defence against the *shomen uchi* attack with an open hand strike downward in a vertical plane. The biomechanical analysis is based on the same rules of mechanics as the techniques referred to above. Figure 8 shows the forces of F and G_1. Similarly to the situation in Figure 7, stepping out of the line of the attack produces the centrifugal force F, whereas his correct hand movement (ended downward) adds force G_1. As a result force F_{w1} is generated. The defender, by grasping the attacker from behind with his second hand, causes that the second resultant force is produced (as in the situation illustrated in Figure 7), F_{w2}. Unfortunately, it was not possible to mark this force in Figure 8. In kneeling positions stepping out of the line of the attack is rather limited due to a smaller speed of movement in comparison with the movements of standing practitioners. Some of the techniques executed in this position require mastering a special method of moving around, namely *shikko*. This method of moving around can be adequately adapted depending on the degree of motor dysfunction of a disabled person. It has been shown that using this method of moving around along with the selected aikido exercises can have a beneficial effect on the health of children with pelvis placement disorders in frontal plane, as well as with a lower degree scoliosis [15-18].

Figure 8. Defence in the *hanmi handachi* position against an open hand attack in a vertical plane (published in [14])

3.3. Execution of aikido techniques by people in a wheelchair

The possibility of making a quick move when sitting in a wheelchair is limited. As far as aikido techniques are concerned, such people can only do a leverage. This mainly means locking wrist joints. An example of this technique is shown in Figure 9. The defender is trying to grasp the hand of the attacker, then he performs a *kote gaeshi* leverage which means wrist twisting. The possibilities of using aikido exercises for the disabled have been confirmed by Rugloni [19].

Figure 9. Defence against a fist attack by doing *kote gaeshi* (published in [14])

4. Materials, methods and experiment results

4.1. Experiment I

4.1.1. Materials and methods

The experiment started in September 2000 and involved 200 pupils (15-16 year olds) attending six secondary school first classes (secondary grammar school and secondary technical school) from a city in Poland [1,2]. The classes were randomly chosen. Mechanics is a part of the first physics class in the course. Physics was taught in four classes (one in the secondary technical school designated for the purpose of the experiment as F and three in the secondary grammar school designated as C, D, E) with a total of 137 students being taught by explaining the principles of mechanics with examples taken from sports practice and by simultaneous explaining the execution of particular motor activities of the given sports techniques, viewing their dynamics from the perspective of physics. Physics in the other two control classes (one in the secondary grammar school designated as A and the other in the secondary technical school designated as B) with 63 students in total was taught using a traditional method. The physics course in classes A, C and D contained one hour of teaching and in classes B, E and F two hours of teaching. The classes A, B, C, D and E were coeducational (mixed), whereas F was boys only. Both groups used the same class books recommended by the physics curriculum for first class technical and grammar school students, however, in the test group many task examples had slightly different contents. This meant that, for example, a task instruction "a body moves down an inclined plane" was replaced with "the ski jumper Adam Małysz skis down the ski-jump". A part of such examples was taken from the book references on sports biomechanics. Before the experiments started at the beginning of the school year 2000/2001, the experimenters checked the subjects' knowledge of mechanics that they had acquired in elementary school and the degree of their understanding of the dynamics of the randomly selected sports techniques in terms of mechanics. The test in mechanics aimed at checking the students' understanding of the principles of mechanics and not their total knowledge of this subject, for example, in a form of a definition included in a particular unit of the physics course. A similar test was carried out at the end of the school year, after the students had completed the mechanics course. Both tests were unannounced and when doing them students could use the formulas covered by physics reference tables or written down by a teacher on the blackboard. The experiment also involved researching the influence of teaching mechanics on the progress achieved in sports performance exemplified by putting a 5 kg shot. 25 boys from the second class of a secondary grammar school were randomly selected for the experiment (16-17 year olds) from the same area as the subjects from the first classes. Firstly, the boys' results in shot putting facing sideways were checked. Then, they were taught the putting mechanics. The experimenters explained what principles of mechanics affected the range and on what motor activities attention should be focused in order to improve to shot put. They also learned why, in terms of mechanics, the shot putting technique facing sideways results in a smaller range than facing backwards or why it is smaller than in a rotational technique. Basing on book references, the students acquired theoretical knowledge of the shot putting technique and its mechanics. In the next PE classes they were taught shot putting facing backwards with the stress put on understanding the technique by explaining it with the principles of mechanics. After three weeks students did a written test in shot put mechanics, which merely checked their understanding of the rules, and then the results of shot putting facing backwards achieved by students of the test group were checked. The tests were carried out in comparison to the initial tests, weather and time conditions. The results were analysed by the analysis of variance. In the first test the significance of differences was established by means of the 't' Duncan test, whereas in the second test a relation between an increase in the shot put range and the degree of mastering the putting mechanics was established by means of the analysis of regression with $p<0.05$.

4.1.2. Results

4.1.2.1. Effect of teaching physics based on sports practice examples on the degree of acquiring the knowledge of mechanics required by the curriculum

The average score in the written test carried out at the beginning of the school year was rather poor (2,0) and no significant differences among students from various classes under analysis were spotted. After completing the course in mechanics required by the curriculum of the secondary grammar school first class, the experimental group that was taught physics with examples from sports practice achieved a significantly higher test score average than the control group that was taught in a traditional way (Fig. 10). The score scale was from 1 to 5, where the worst score was 1 and the best was 5.

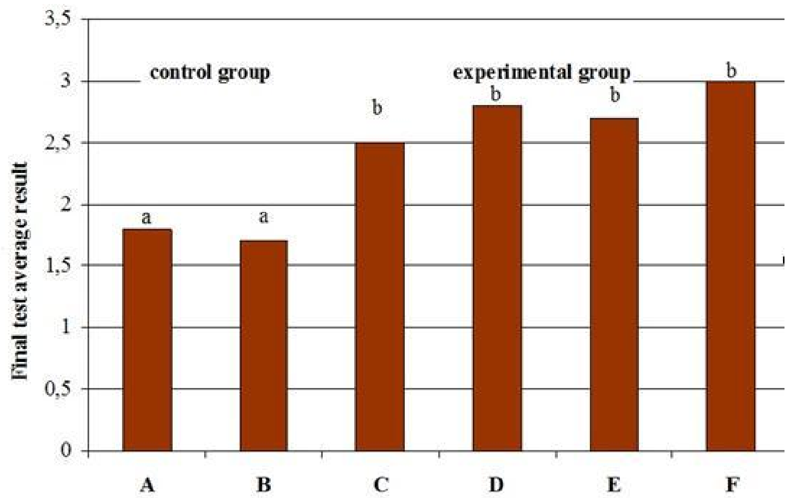

Figure 10. The average score in the test - in mechanics reached by students taught physics in a traditional manner (control group) or basing on the sports practice examples (experimental group). The averages marked with different letters differ from one another according to the ‘t’ Duncan test with p<0.05 (published in [1])

In the experimental group, students’ skills in explaining the correctness of executing certain motions in the selected sports techniques with the principles of mechanics was also checked. It was found that at the beginning only 22% of the subjects possessed these skills, whereas at the end of the experiment this value grew to 78%.

4.1.2.2. Effect of the intensity in teaching physics on the degree of acquiring the knowledge of mechanics required by the curriculum

Contrary to the expectations, increasing the number of physics classes from one hour to two hours a week did not significantly improve students’ understanding of the principles of mechanics, both in the control as well as in the experimental group (Fig. 11).

4.1.2.3. Effect of teaching mechanics on the range of shot put

A clear relation between sports performance results and the degree of mastering the theory was found in the group of pupils to which the shot put technique was explained with the laws of mechanics (Fig. 12).

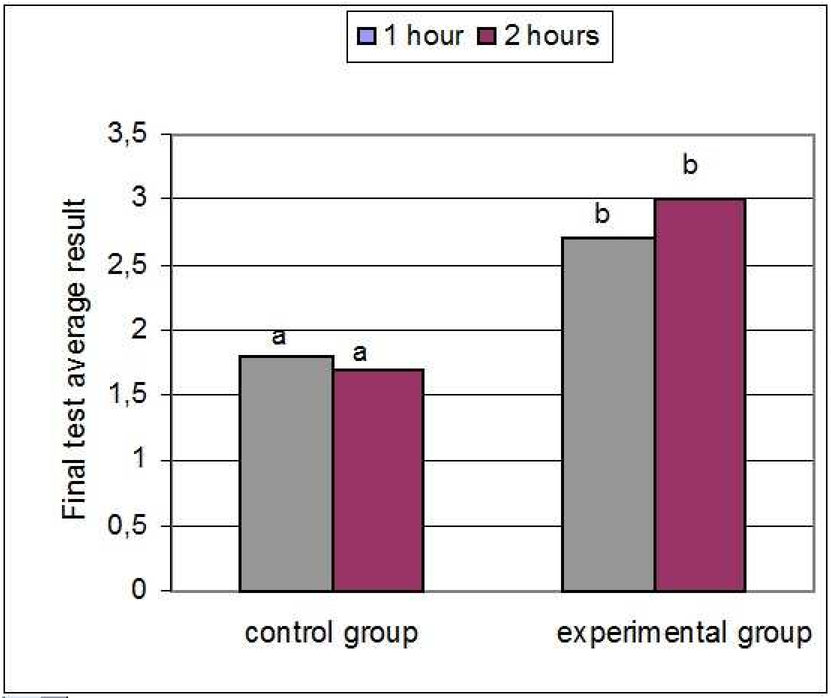

Figure 11. Effect of the method of teaching physics and its intensity on the degree of acquiring the knowledge of mechanics by pupils. The averages marked with different letters vary from one another in accordance with the 't' Duncan test with $p < 0.05$ (published in [1])

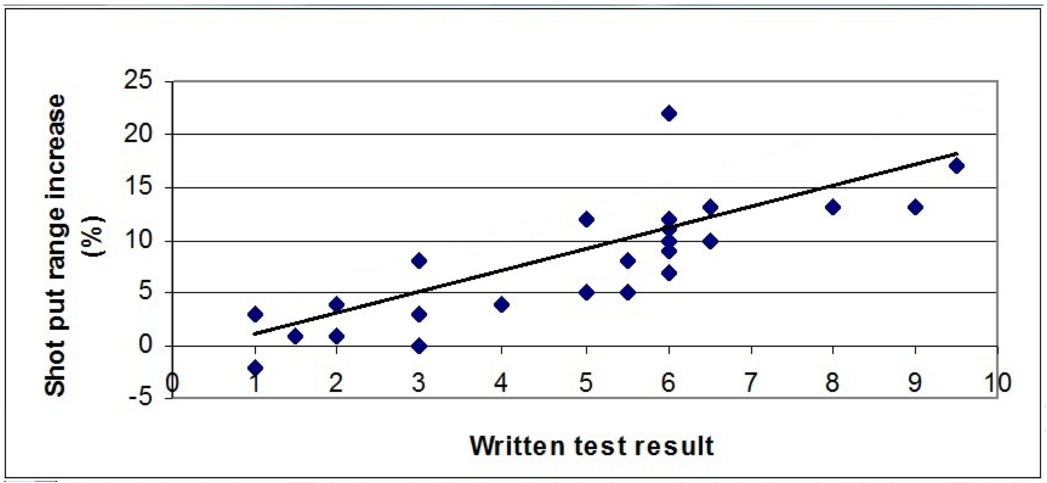

Figure 12. A relation between the shot put range increase and the results in the written test in mechanics (y=2,26 + 3,24x, r=0,83) (published in [1])

The score scale for the written test in mechanics was from 0 to 10. The putting range increase was expressed as a relation between the shot put range increase (Δy) after completing the course of this put mechanics and the range (y) reached at the beginning of the experiment. During the test 23 students out of 25 performing the test tasks improved their sports result, one got the same result and in one case the participant's result was slightly worse. A strong relation between relative shot put range increase and results in the written test in mechanics was found. This is confirmed by the high value of the correlation factor r=0,83 obtained. After doing the theoretical test and after completing the practical test in shot putting, the students reported in writing on what elements of their technique facing sideways needed improving in terms of mechanics. It turned out that 87% of students were able to state what they should improve.

4.2. Experiment II

4.2.1. Materials and methods

The samples for the study consisted of two groups of secondary school students from a city in Poland [2]. All subjects had participated in similar studies in the school year 2000/2001 [1]. The two study groups were in fact two school classes E and F. They were 17 and 18 years old. Group E (control group) comprised 33 students and group F (experimental group) included 27 students. In the first semester of the school year 2001/2002 group F (second secondary school grade) practised aikido one hour a week in an additional PE class. Solid-state mechanics is part of the physics curriculum in the third grade of secondary school, after students acquire sufficient mathematical skills in their lower grades. Before the commencement of the mechanics course in the school year 2002/2003 students had to pass a physics revision test covering material from the first grade, i.e., translational mechanics (test 1). Solid-state mechanics was taught in class E in the traditional way, whereas students from class F used their experiences and examples from aikido acquired during the additional PE class. This mechanical movement was also compared with other sports techniques used in diving, sports gymnastics, dancing, figure skating, etc. Both groups then took a final test to assess their learning outcomes. Both tests (1 and 2) were surprise tests and were carried out sometime after the last class to ensure assessment of students' understanding of the mechanics principles, and not merely their memorizing skills. During the additional PE hour the F class practised aikido. The teacher explained the dynamics of aikido techniques using the principles of biomechanics. He also explained what biomechanics dealt with and what relation it had with the mechanics taught at school. The students were told that biomechanics applies the rules of mechanics in analysing human movements. In describing this movement the human body is divided into 14 parts treated as solids [20]. The classes focused mostly on the solid-state rotational mechanics. The participants were informed about the advantages of reduction of the radius of performed movements, the distance between the arms and the axis of rotation, or of lowering or optimal shifting of the body's centre of gravity. The principles of aikido, such as "yield to win", "turn around if you're pushed" or "move forward if you're pulled", were explained to the students using the law of momentum conservation, second law of motion for angular motion, centrifugal force and composition of resultant forces and moments of force [6, 7]. The students' knowledge of biomechanics for aikido was tested in essay form. This test checked students' understanding of executing motor activities involved in the techniques performed with the rules of mechanics. After writing their essays, the students got acquainted with four selected aikido techniques over a one month period. The selected techniques in the form of their performance made it possible for a defender to use the centrifugal force acting on the attacker, as well as their mass as in Figures 6 and 7. Then the precision of performance of each technique was assessed using a ten-point scale. Each subject could score up to 40 points. The method of evaluation of aikido technique performance was taken from the Koichi Toheia aikido school. As sports rivalry does not in principle apply in aikido, practitioners are evaluated on their performance of *taigi*, i.e., sets of techniques executed in response to a particular attack. Both the precision and speed of movements are evaluated. During the study only the precision of movement sequences performed by a practitioner was assessed. The precision criteria included an appropriate reduction of the radius of motion, assuming proper body posture, arms movement and shifting of the body's centre of gravity during a given movement. Before learning the selected techniques, the students taking part in the test had already acquired basic aikido skills, i.e., safe falls, body turns and rotations. The assumed method of instruction was "from the general to the specific" [2,7,21]. This method stresses first of all synthetic teaching by explaining the general rules of technique execution which is only then followed by an analytical study of particular movement sequences in a given technique.

4.2.2. Results

The effects of the mean results of the written tests in both groups were assessed using the student t-test for independent variables. No statistically significant differences were observed between group E and group F in test 1, but not in test 2 ($p < 0.05$) (Fig. 13), where group F attained a much higher mean result than group E. The obtained student t-test results were confirmed by results of the non-parametric U-Mann Whitney test.

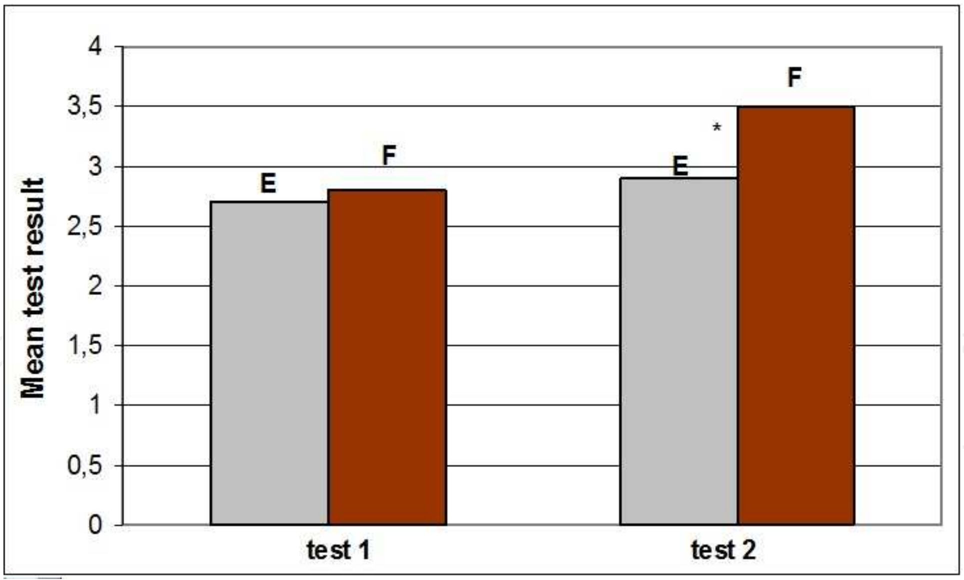

Figure 13. The mean results of mechanics tests taken by students from group E (taught in the conventional way) (n = 33) and from group F (taught using examples from aikido and other sports) (n = 27) (published in [2])

The analysis of regression was used to examine the correlation between the correctness of the biomechanics test answers and the precision of performance of aikido techniques. A strong correlation was noted between the two at $r = 0.9$.

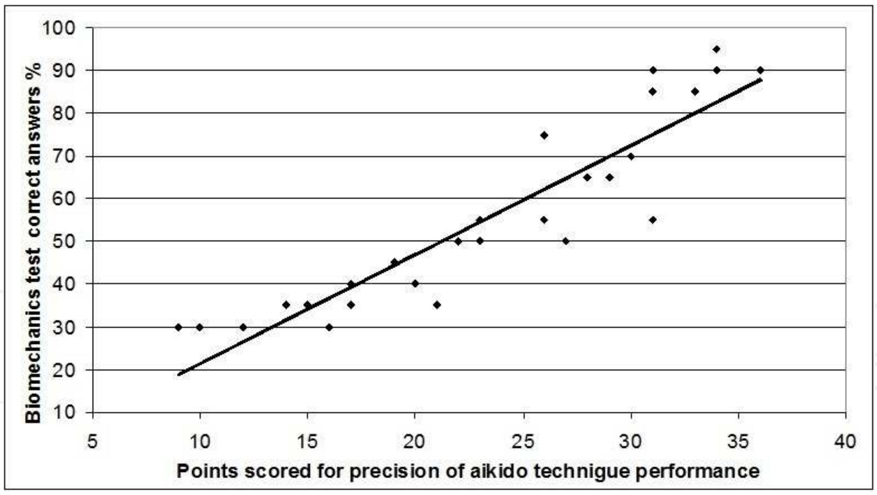

Figure 14. Correlation between results of the biomechanics tests and points for precision of performance of aikido techniques. Equation of the regression line: $y = -4.10 + 2.56\ x$, $r = 0.9$ (published in [2])

4.3. Experiment III

4.3.1. Materials and methods

The research involved fourth form pupils at a primary school from a town in Poland aged 10-11, divided into two 25-strong training groups (A and B) [7]. The pupils were selected at random. The two groups thus formed were representative enough for the whole of the school's pupil population. The pupils at the school came from one district, so the groups were homogenous because the pupil qualification to separate into groups was based on random selection (selection does not considered special skills, intelligence, material or social status, achievements of previous education years etc.). The experiment was performed during the first term of the school year of 2001/2002. Similar research methodology used to teach aikido to secondary school students was used to teach primary school students [2]. However, due the difference in age of the participants, the methods were slightly modified. The subjects practised aikido at extra-curricular PE classes. Having mastered safe falling - necessary for the practice of aikido - the pupils were taught four selected aikido techniques over a period of one month. Different methods of teaching were applied for particular experimental groups. A were taught using the 'general-to-specific' method [7,21], whereas B were taught using the 'specific-to-general' method, with the analytical approach prevailing. Successive movements of a particular technique were taught. Only after the children mastered the particular movements, were they taught to put them together in order to perform a particular technique. The children learned the movements by following closely the instructor's movements. Group A were taught using the 'general-to-specific' method, with the prevalence of the synthetic method: for instance, teaching a particular technique's proper movements involved decoding the motor abilities the children already possessed. A good idea is, for instance, to enact a "crowded underground station". The trainees occupy a small space in a room thus making an artificial crowd. At a signal they start moving fast. It can be seen that some of them, in order to avoid a collision with others, in a natural way make turns and revolutions. It may happen that they have already mastered the proper way of turning and revolving - and they only need to retrieve it. During the instruction, the instructor first tried to find out which turns and revolutions the children had already mastered. Next, he showed how to use them in a particular aikido technique. Only the lacking abilities were taught from scratch. Group A was taught aikido, drawing on the knowledge of biomechanics [6]. This was a completely new thing to the children since physics is not included in the primary school curriculum. The techniques were explained by, for example, quoting the second principle of dynamics of rotary motion, the principle of conservation of angular momentum or the factors influencing the value of the centrifugal force. Because the children at this age have no mathematical knowledge that would allow them to understand the principles in the form of formulae, the particular laws of physics were taught by means of experiment presentations, without the use of scientific terminology. Instead, children's language was the one of instruction. The presentations included observing a top spinning. The children played 'top fights' on special boards, by making the tops move in such a way so that that the top's motion imitated some aikido techniques. However, they were also made aware that those techniques also involve vertical motion - resembling a top which suddenly rises or lowers its position while spinning. The children were told that this additional upward movement enables the practitioner to take advantage of his mass while performing a defensive technique. Next, the children were shown a sample technique involving this kind of motion. The children were also allowed to try and execute the technique - imitating the movements of a top. Referring to biomechanics, the instructor explained aikido teaching principles [6,21], such as 'turn around if you are being pushed', 'go if you are being pulled', or 'give in to win'.

After experimental interpretation of the principles of mechanics present in aikido techniques, Group A children were tested for their understanding. By asking questions and using questionnaires, the children's understanding of the movements in aikido techniques was assessed basing on the experimental interpretation of the rules of mechanics covered. A sample question went: 'Using knowledge of biomechanics, how do you move a particular body part in order to execute a particular aikido technique most effectively?' After questionnaire-based oral testing in Group A, both groups were taught four aikido techniques. This research method was also used by this author when carrying out research on secondary school students [2]. After one month, the children were tested for their execution of the techniques. Similarly to the situation of secondary school students, the assessment focused on the effectiveness of execution of a particular sequence of movements, regardless of the tempo which was to be slowed down. The tempo of the attacker was adjusted so that the defender could execute all the successive movements of a particular technique. The correctness of the execution was assessed by this author using a 1-10 point score scale. The maximum score was 40 points. To analyse the findings, mathematical statistics methods were used, including analysis of regression and student t-test for the independent variables. Analysis of regression was used to find out about the correlation between the correctness of answers to questions concerning biomechanics and the correctness of aikido technique execution. The relation between the scores for the execution of aikido techniques and the type of group was examined using student t-test for the independent variables.

4.3.2. Results

Group A achieved a much higher arithmetic mean than group B (Fig. 15) as far as aikido technique execution is concerned. It was also found out that the results achieved for both groups differ statistically ($p<0.05$). A high statistical significant correlation coefficient ($r=0.75$ for $p<0.001$) was found between the correctness of the answers to questions concerning biomechanics (Fig. 16). This is confirmed by a high value of the correlation coefficient r=0,75.

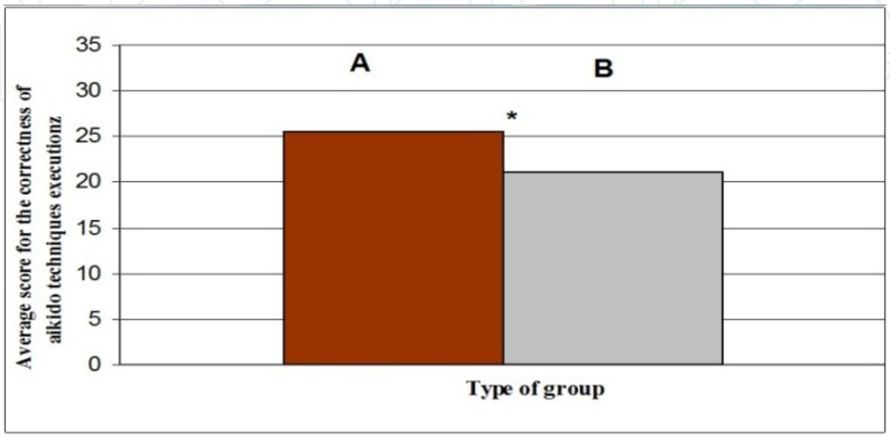

Figure 15. Average scores of children in both experimental groups (A and B) for the execution of aikido techniques (*p<0.05) (published in [7])

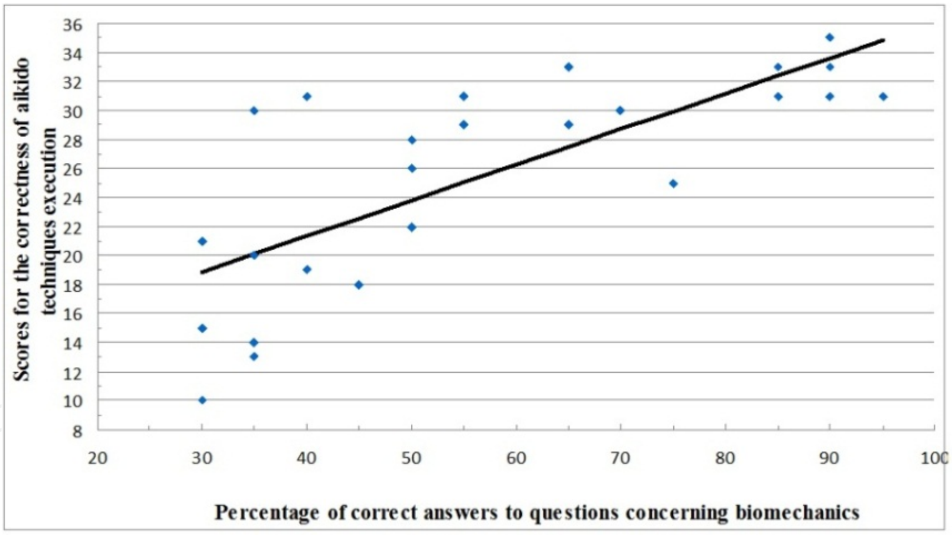

Figure 16. Correlation between the scores for the execution of aikido techniques and the correctness of answers to questions on biomechanics in Group A (n=25). Simple regression equation: $y=11.538+0.245x$, $r=0.75$ (published in [7])

5. Summary

5.1. Mastering the knowledge of biomechanics

The results of Experiment I show rather poor average results achieved by the participants in the mechanics test, especially in the first test that covered the elementary school course of this subject. This may be explained by the fact that it was not an easy test, because it checked understanding of the principles of mechanics. Since it was a surprise test it checked students' durable knowledge rather than the information they could remember from lesson to lesson. Such knowledge is based on understanding, most conveniently backed with examples that stay in one's memory, like sports examples. A student, remembering an interesting case will always refer it to the principle of mechanics related to that example. It is interesting that in a control group the average score in the final test lowered as compared with the results of the test the students did before the commencement of the experiment, whereas in the experimental group the final test results were better than the results of the first test. However, the comparison of the results of both tests should be treated as some kind of simplification. First of all, the initial test checked pupils' knowledge of mechanics on an elementary school level, whereas the final test checked this knowledge acquired by first class secondary school pupils. Nevertheless, in both tests understanding the mechanics and not learning rules was focused upon. Thus, the fact that the control group classes got lower results in the final test than in the first one, does not mean that they did not make any progress. It is certain, though, that pupils in the experimental group made much greater progress in understanding the principles of mechanics in comparison with the control group. The boys' class achieved the highest average score, however, the difference between their results and the results of mixed classes in the experimental group was not statistically significant. This leads to the conclusions that examples based on sports performance are equally attractive to boys as to girls. It is intriguing though that increasing the number of classes in physics a week did not affect the average score a particular class got in the test. Thus, the conclusion is that for understanding the rules of mechanics the subjects needed only one hour of physics a week. A significant factor resulting in increasing the test result was definitely a more attractive method of teaching. A great difficulty in teaching physics at school is the fact that pupils' knowledge of mathematics used for describing the laws of physics is not satisfactory. Usually, owing to a small number of classes a week, physical experiments are done by a teacher in demonstration form and pupils cannot practise doing them by themselves. Sometimes, a pupil is required to learn definitions by heart instead of focusing on understanding them. All this leads to a situation in which it is hard to achieve the most important goal, that is to make pupils interested in the school subject they are being taught. The test results show that pupil learning of the principles of mechanics is facilitated by using sports examples, which generates their increased interest. A pupil performs in a PE class a mechanical movement. The only problem is to make him aware of the fact that it is a perfect experimental base which can be referred to during classes in physics. There was no statistically significant difference between the two groups of students (E and F) participating in Experiment II in terms of their results of mechanics tests in the school year 2000/ 2001(experiment I), their average scores were similar. This was confirmed by the results of the written test taken by the students before the start of the solid-state mechanics course (test 1). It shows that both groups had similar conditions for learning the mechanics material. A new method of teaching solid-state mechanics significantly affected the differences between the results of solid-state mechanics learning attained by both groups of students. In a traditional physics class a teacher demonstrates an experiment using the equipment of the physics study. In the author's opinion the main factor affecting the results in group F was students' participation in aikido classes, during which aikido techniques were explained using the principles of mechanics. The students' participation in aikido classes could facilitate their understanding of mechanics principles, following the educational rule of affecting as many of the students' senses as possible [2,7]. The PE classes as well as other forms of extra-school physical activity allowed more active contribution of other senses – including somatic ones – to the learning process, than hearing and sight only. The obtained results correspond to the results obtained in experiment I. Learning the laws of mechanics by school students could be greatly facilitated by the use of examples from sport and other extracurricular physical activities [1].The experiment III differs from the previous study in the way the knowledge of biomechanics was conveyed. The previous study made use of the mathematical formulae describing the principles of mechanics which the students had come to know in physics classes. This was all but impossible in the present research, since the pupils had not had physics at school yet. The analysis of the questionnaire used in the experiment leads to the conclusion that the methods used for teaching particular aikido techniques facilitate children's understanding of the laws of physics describing rotary and translatory motion. Children may learn to predict the results of sudden changes of the direction of their movement, e.g., turning suddenly while running straight. In this way they may learn about the forces involved in such changes and about ways of using those forces for a particular purpose.

5.2. Effect of mastering the knowledge of biomechanics on technique execution

The results obtained in the shot put (experiment I) lead to the conclusion that the increase in the results was caused by turning from the shot put facing sideways to the technique of facing backwards. It should be excluded that the increase in the result was affected by an increase in the pupils' fitness, because in such a short period of time (3 weeks) the group participating in the test could not improve it to a great extent. The range increases achieved were caused by changing the putting technique. The results in experiment II and III show that the aikido techniques were mastered best by those who were better at understanding the principles of mechanics involved in the techniques, from which it follows that it is justified to explain how to perform a particular technique quoting biomechanics. The concept of motor teaching which relies on the awareness and understanding of the task while learning a specific move, proposed by Bober and Zawadzki [20], appears to be a valid one, too, with regard to the teaching of aikido to children. Such a teaching method not only facilitates the repetition of already mastered moves, but also helps invent new ones according to the needs. In experiment III the aikido classes employing the "general-to-specific" method resulted in a better mastering of aikido techniques than the ones based on the "specific-to-general" method – as is confirmed by Group A's higher average score for the execution of aikido techniques, compared with Group B. Thus, the synthetic way of teaching the execution of the techniques gave better results than the analytic teaching of successive moves involved in a particular technique [2,7,21]. With Group A, an experimental interpretation of the laws of mechanics, describing rotary and translatory motion of the human body, was used. In this case the interpretation relied mainly on using the partner to explain the laws of physics governing translatory and rotary motion. Performing a particular aikido technique with a partner gives one an opportunity to feel the effects of the force exerted on the partner and vice versa. Such a possibility to experiment has been noted by Kalina [22]. According to him, what X aikido student experiences from Y aikido student, will in a moment be Y's experience from X . Such participation in mechanical motion may help one understand mechanics - in compliance with a pedagogical permanence principle of 'stimulating most of a learner's senses' [2,7]. The instruction based on the use of the knowledge of physics in martial arts may not only be used with techniques, but also to teach safe falling. Simple falling experiments with a notebook or a cushion [7] may explain the principles of safe falls in judo or aikido - by showing how a falls' mechanical energy can be reduced by increasing the body surface that hits the ground [23, 24]. A show experiment may improve the child's understanding of the importance of positioning oneself properly while falling. The method adopted for the needs of this experiment did not require the children to display motor abilities at a certain level because of the form of instruction, a presentation of the execution of techniques. This researcher's assessment method applied to a slowed-down execution of aikido techniques, which was necessitated by the need to limit the effect of the subjects' motor fitness upon the effectiveness of execution. Besides, in the process of movement management slow movements allow so-called "feedback", the presence of which can be detected not only after the execution of a movement, but also during the execution [20,25,26]. This allows for managing movements during execution. Practising self-defence develops psychomotor abilities [27]. The basic psychomotor ability which depends on the knowledge of biomechanics is the ability to choose a proper method of defence. Coaches and PE teachers may have problems in requiring from their pupils to apply the mathematical apparatus (knowledge) in interpreting the rules of mechanics. This may be a result of the fact that the skills that pupils have acquired at school are not satisfactory and in addition they are reluctant to apply physics formulae. However, there is the possibility of using the knowledge of biomechanics in the teaching methodology of various sports disciplines. This type of the knowledge can be provided experimentally, as it was shown with aikido [2,7]. In the author's opinion this knowledge is always decently applied by PE teachers. It is advisable to incorporate a biomechanical analysis of sports techniques into teaching and not only limit to giving instructions to a pupil to lift, for example, a certain limb. Teaching an infinite number of motor sequences requires learning about the rules managing the rotary and translatory motion [2,6]. The role of a teacher or educationalist is to know these rules, because they may facilitate mastering certain motor activities by exerting an effect of understanding them based on these rules. The results obtained in experiment III show that martial arts can develop children's cognitive skills as well their motor skills [7]. In view of the above, the belief that martial arts can develop both body and mind seems justified. This, according to the author, supports Prof. E. Jaskólski's suggestion to carry out more detailed research into the way martial arts could be used in education [7, 21]. Unfortunately, there is a tendency at the moment for some of the martial arts to develop sports-wise, thus becoming ever more offensive rather than defensive [22,28]. Extreme offensiveness may border on aggression, which may result in abortion of judo philosophy and make martial arts less useful for pedagogical purposes.

5.3. The most recent research

The effect of the knowledge of mechanics on execution of aikido techniques was also analysed after testing PE students (university students, Mroczkowski A., unpublished). Similar correlations between this knowledge and aikido techniques execution as in the experiments referred to above were found. The experiment participants were also tested to find out whether understanding the rules of mechanics of a rotational movement can be related to applying aikido techniques in simplified forms of sports competition. The main objective of the experiment was to check if aikido practitioners are able to use the force of their opponents. Competition was based on similar rules to sumo, but in the apparel typical for judo competitions. Similarly to sumo, pushing a practitioner out of the bordered fight area or touching the surface with anything other than a foot body part, meant losing the game. A correlation between the knowledge of biomechanics acquired and success in the sports competition was not established (Mroczkowski A., unpublished). The results achieved could have been affected by several factors. Definitely, the short time of training, decided upon as in previous experiments [2,7], influenced the results. It is obvious that only knowledge of biomechanics is not enough for a correct execution of a certain technique with great speed and optimum dynamics. It is necessary to develop a child's correct motor features and this requires a relatively long period of time. The final success in a fight, according to Starosta and Rynkiewicz [29] is also affected by "feeling" the opponent. Thus, according to the author, the aikido forms involving a certain sports competition, sometimes similar to judo forms, should be focused on [30]. This may give a certain control over development of motor features necessary for practising in the right time techniques depending on the changing, for example, attack of the opponent. The author is presently dealing with the analysis of the effect of understanding the rules of rotational motion mechanics on mastering motor activities in rotational techniques not only in aikido, but in various sports disciplines, such as sports gymnastics, break dance and trampoline. For this purpose a training rotational simulator was used [31] (patent pending). This device is composed of two platforms on which students experience rotational movement. They can assume various body positions, for example, standing or lying. The subjects simulate the body positions assumed in sports techniques. Figure 17 shows an example of applying this device.

The whole platform on which a student is standing starts rotating. After gaining a certain velocity, the platform is no longer driven and the whole movement goes on almost without friction. A subject, for example, grabs the two bars (Fig. 17) which can imitate grasping certain parts of the opponent's body or clothes. When changing the distance between the centre of mass and the axis of rotation of the training simulator, the subject gains a change in an angular velocity according to the second law of dynamics of rotational movement. The subject is feeling the changes in angular velocity when he is changing the distance between his body and the axis of rotation. This is a good situation in which to explain to him the analogy of this movement to the aikido technique executed. Two people can practise on the rotating platform at the same time. With this device it is possible to determine the moment of inertia of the subjects if their centre of mass is located on the axis of rotation of the training simulator. For this purpose the rotating platform is driven with a falling weight. This method was already used by Griffiths et al. [32]. The initial results (Mroczkowski A., unpublished) show that the method of the experimental explanation of the principles of mechanics of the rotational movement facilitated their quicker understanding by the subjects participating in the experiment. At the same time, exercising on this device quickened the process of mastering the correct motor habits necessary for executing some aikido, break dance, trampoline and sports gymnastics techniques.

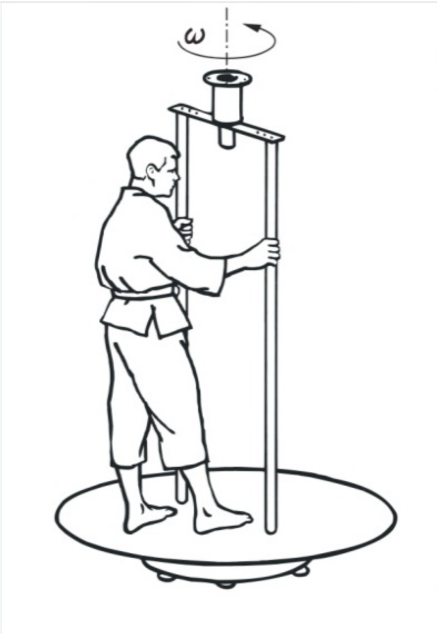

Figure 17. An example of applying the rotating training simulator

The analysis of the tests covered by the experiment raise a question: ‘Isn’t it worth applying biomechanics in teaching mechanics as part of the school curriculum in physics?” Biomechanics is for the author a form of so-called “live mechanics”. It deals with a human being, his movements or his functioning in terms of mechanics. As the tests referred to in this paper show, this knowledge of mechanics provided in this form is well acquired by adolescents and children. It is advisable to consider whether it is possible to teach other parts of physics in this way. The author thinks that some parts of physics would prove to be useful here. For the majority of adolescents and children it would be interesting to explain the rules of their body functioning in terms of physics.

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