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Original Article

MEANINGFUL LEARNING OF BIOMECHANICAL CONCEPTS: AN EXPERIENCE WITH PHYSICAL EDUCATION TEACHERS IN CONTINUING EDUCATION

APRENDIZAGEM SIGNIFICATIVA DE CONCEITOS BIOMECÂNICOS: UMA EXPERIÊNCIA COM PROFESSORES DE EDUCAÇÃO FÍSICA EM FORMAÇÃO CONTINUADA

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RESUMO

O conhecimento biomecânico é essencial à prática profissional dos professores de Educação Física, porém, ainda é pouco aplicado por eles. Este estudo, de abordagem mista e do tipo intervenção pedagógica, avaliou um curso de formação continuada, baseado na Teoria da Aprendizagem Significativa, cujo propósito foi favorecer a compreensão de princípios biomecânicos e suas aplicações. A análise estatística foi realizada para comparar pré-teste e pós-teste e, a análise de conteúdo, para categorizar a avaliação do curso realizada pelos professores. Os resultados apontam aumentos significativos no domínio dos conceitos biomecânicos pelos professores. Percepções positivas das aulas como a interação social e aplicação prática do conteúdo foram relatadas. As dificuldades estiveram relacionadas à falta de conhecimentos prévios e de tempo para estudar.
Palavras-chave: Desenvolvimento profissional. Ensino. Avaliação.

ABSTRACT

Biomechanical knowledge is essential for professional practice of physical education teachers, but it is still little applied by them. This study examined the effectiveness of a continuing education program based on meaningful learning theory to improve understanding of biomechanical principles and their application by physical education teachers. A pedagogical intervention study was developed using a mixed methods approach. Statistical analysis was performed to compare pretest and post-test scores, and content analysis to categorize the teachers' evaluation of classes. The program created significant increases in mastery of biomechanical concepts in teachers studied who had strong perceptions of the course, peer interaction, and application to professional practice. Difficulties perceived were related to lack of time to study and prior biomechanical knowledge.
Keywords: Professional development. Teaching. Evaluation.

Introduction

When we consider that kinesiology/exercise and sport science knowledge is constantly advancing, continuing education (CE) has a fundamental role in the professional development of physical education teachers. CE in physical education is not just a matter of reinforcing key knowledge from the undergraduate degree, but also providing opportunities for updating this knowledge and improving pedagogical skills to teach more effectively. Furthermore, professional development programs should engage teachers in collaborative and reflective practices, and help them to become lifelong learners[1].

A biomechanics course is required in most all undergraduate kinesiology/exercise and sport science/physical education degrees throughout the world. In physical education, biomechanics informs professional practice through improved understanding of human movement, the relationship between the forces of the body and those acting on it that cause movement, and the application of this knowledge to prevent injuries or to improve the movement[2]. Biomechanics is particularly helpful to physical education teachers in qualitatively evaluating and diagnosing movement technique[3] and developing instructional plans consistent with students' skills. In addition, from the perspective of education about movement[4], simplified biomechanical concepts of movement and sport skills can be integrated in school physical education classes as academic content to help students understand the technique of the movements and sports skills performed[5]. The education through movement[4] in school physical education may use the engaging medium motor skills as a teaching strategy to connect physical and biomechanical concepts to the students' real-world experiences[6].

Although biomechanical knowledge is essential to high-quality physical education instruction, there are several barriers to its implementation. Physical education majors often fear and dislike the biomechanics course[7] and considerable research indicates student mastery of biomechanics concepts are moderate[3] and similar to traditional physics instruction[8]. Biomechanics is, therefore, rarely used consciously by many physical education teachers in their daily practice. This has led to the development of CE programs to reinforce knowledge of biomechanical concepts and their application for physical education teachers[9] or student teachers[10].

Effective CE programs are typically based on a constructivist philosophy of learning. From this perspective, learning is a personal and intentional process of construction and reconstruction of knowledge in which teachers create learning environments to help students negotiate and grasp content meanings[11]. According to Ausubel[12], although meaningful learning and rote memorization are on the same continuum of content mastery the first only occurs when a person associates a new idea or concept, in a non-arbitrary (non-randomly) and substantive (non-literal) way, with a relevant prior knowledge in his/her cognitive structure. Rote memorization allows little or no acquisition of new meanings by learner. Although memorization may be useful in several situations in daily life, the specific memorized content is hardly used in situations that require more complex knowledge or application in different contexts. This is reinforced by many studies indicating the importance of planning and implementing pedagogical actions to provide learning environments that foster meaningful physical education experiences[13-15].

Ausubel[14] also stated that meaningful learning occurs when the instructional material has potential to be assimilated by learner, who must also have the disposition to establish meaningful conceptual relationships. This can be a problem given many students prefer memorization to more nuanced engagement in conceptual relationships. In undergraduate biomechanics, for example, many students believe that memorization of unrelated specific biomechanics facts is the best way to learn[16]. This often follows from the student's having to emphasize memorization of an extensive amount of anatomical structures and terms, that may be associated with students' difficulties learning biomechanical concepts[17].

Meaningful learning theory[11,12,18] also offers fundamentals to plan, develop and evaluate instruction. According to Novak[18], student, teacher, content, context, and evaluation are all dynamic elements that interact with each other in the educational process. Related to these elements, social interaction is essential to foster students' negotiation with, sharing and grasping of conceptual meanings and thus, acquire knowledge with personal meaning[11]. In addition, social interaction is also a principle to support pre-service teachers in learning how to facilitate meaningful physical education experiences[14].

One study proposed a CE program teaching biomechanics to physical educators based on these principles of meaningful learning[9]. This continuing biomechanical education program has not been tested for effectiveness and research is needed. The purpose of this study was to examine the effectiveness of the Belmont, Knudson, and Lemos[9] biomechanics CE program on improving understanding of biomechanical principles and their application by physical education teachers.

Although learning is influenced by many factors, it was hypothesized that a CE program based on meaningful learning theory which uses pedagogical strategies to encourage social interaction and reflection about knowledge and its application, could promote significant improvement in teachers' biomechanical knowledge.

Methods

Context and participants

A pedagogical intervention study[19] was developed using a mixed-methods approach and the meaningful learning theory[11,12,18] was the major theoretical framework.

A CE course for physical educators who teach in elementary and high school in Brazil was implemented based on program proposed by Belmont, Knudson, and Lemos[9]. The program engaged educators in reviewing and learning five of nine biomechanical principles proposed by Knudson[2] as Force-Motion, Range of Motion, Optimal Projection, Inertia and Balance using the professional skill of qualitative diagnosis (Preparation, Observation, Evaluation/Diagnosis, and Intervention) of motor skills[3]. A review about biomechanical content to introductory biomechanics courses suggests that Knudson's biomechanical principles are compatible with meaningful learning theory[20]. Because principles express conceptual relationships, they are essential for students' meaningful learning[12]. Real-world human movement problems were proposed to help teachers to understand the relationship between biomechanics and their professional practices. Teaching strategies aimed to promote social interaction, negotiation, and share conceptual meanings discussed in class.

The 25-hour course was held at Oswaldo Cruz Foundation, Rio de Janeiro, and was conducted once a week for a total of 6 days. Seventeen physical education teachers enrolled in the course spontaneously after advertisement by the institution. These volunteers, 9 men and 8 women, varied from 22 to 52 years of age. They had between 1 and 29 years of teaching experience. All participants graduated in the same state of Brazil and had previously taken the introductory biomechanics course in their undergraduate studies. They gave written consent to participate in the study. The research was approved by the Institution's Ethical Committee (n. 613/11) and to ensure confidentiality, participants were identified by random numbers.

Data collection

Quantitative and qualitative evaluation of learning biomechanics concepts were made through collection of audio recordings of all classes, and administration of a pretest and posttest. Teachers' perceptions about and evaluation of the CE classes were obtained in writing for qualitative evaluation. The pretest was given in the first class and the posttest in the last class along with course evaluation.

The test (given pre and post-instruction) consisted of 170 questions evaluating understanding of anatomical and biomechanical concepts (Appendix A). Course concepts were classified into 1 of 10 classes (Table 1) of biomechanical principles common to the introductory biomechanics course[2]. Test content was reviewed and validated by four university faculty with experience in introductory biomechanics courses from different Brazilian universities.

The test items were developed in a way that physical education teachers were not able to solve questions using rote memorization/learning as recommend by Ausubel[12]. Because the course discussed the same concepts as the test, the examples and situations studied during classes were different from the ones used in the test. Open-ended response questions allowed participants to express their answers with own words, excluding the possibility of success by chance (Appendix A). Test questions required, from teachers, reflection about the conceptual relations of biomechanical concepts in physical education.

Table 1. Ten classes of biomechanical concepts/principles identified on the test and 4-point (zero was used for no response) grading rubric used for quantitative scoring

	Conceptual classes/ Relation between	Adequate	Partially adequate	Insufficient
		3	2	1
A	Plane of motion and joint axis in which it occurs	Correct plan and axis with coherent explanations when requested	A correct element or only the coherent explanation when requested	Incorrect
B	Joint motion and muscular group responsible	Muscle groups or each muscle involved correctly	At least one muscle correctly	Incorrect
C	Muscular activity and direction and sense of the motion	Correct type of muscle action	-	Incorrect or more than one type of muscle action
D	Effect of external force and joint motion performed	The resistance to motion correctly and coherent explanation if requested	At least one element of system correctly and coherent explanation if requested	Incorrect or inconsistent explanations when requested
E	The shape of the body and its point of equilibrium	All correct	At least two corrects	Incorrect
F	Angular and linear motion	Explain relationship correctly	Explains part of the concepts involved	Incorrect or mention part of concept without explanation
G	Projectile's trajectory and its projection/release angle	Explain relationship correctly	Explains part of the concepts involved	Incorrect or mention part of concept without explanation
H	Force and its time of application	Explain relationship correctly	Explains part of the concepts involved	Incorrect or mention part of concept without explanation
I	Essential features and biomechanical concepts	Identifies the causes for inadequate movement using biomechanical principles and concepts	Identifies the causes for inadequate movement with at least one biomechanical principle or concept	Incorrect or did not use biomechanical principles and concepts
J	Essential features, diagnosis, and intervention	Intervention consistent with the diagnosis	At least one aspect of the intervention consistent with the diagnosis	Intervention not consistent with the diagnosis

Source: Authors

For the course evaluation, teachers were invited to write about positive and negative points of classes. It was emphasized that evaluation aimed at future improvements in the CE proposal and would not be related to the course grade.

Data analysis

Teachers' answers from pre and posttest were categorized by the first author using qualitative content analysis criteria by Bardin[21]. First, the material was organized, and a floating reading was performed to identify the meaningful conceptual units of the teachers' responses. After that, the researcher coded and grouped the units into 4 ordinal categories that express the level of knowledge demonstrated by students in each class of conceptual relation (Table 1). The 10 conceptual classes were consistent with theoretical framework and principles[2] of the introductory biomechanics course.

The categories were classified from zero to three according to the criteria: Zero, blank responses; One, insufficient; Two, partially adequate; Three, adequate (Table 1) mastery of the biomechanical knowledge in each class. Statistical analyses were performed with Wilcoxon signed-rank test (nonparametric) in IBM SPSS Statistics 22 to compare pretest and posttest total correct scores for each conceptual category. Statistical significance was accepted at the $p<0.05$ level and exact observed p values reported.

The records obtained from teachers' written evaluation of classes were also categorized qualitatively[21]. After floating reading, the meaningful units of content were identified, coded, and grouped in 3 main categories (positive points, difficulties, and suggestions to improvements) that emerged from teachers' writing.

Results and Discussion

There were improvements in teachers' overall biomechanical knowledge from the CE course (Table 2). This change resulted from significant improvements in mastery of 6 of the 10 conceptual classes (Table 3). This indicated the CE course based on meaningful learning theory fostered important advances in teachers' learning for majority of the core biomechanical concepts important in physical education.

Table 2. Conceptual classes responses (17 per class) that express changes in understanding of biomechanical concepts before and after the CE program

Conceptual classes	Pretest %				Posttest %			
	zero	one	two	three	zero	one	two	three
A	5.9	35.3	47.1	11.8	0	0	23.5	76.5
B	0	29.4	58.8	11.8	0	29.4	58.8	11.8
C	17.6	47.1	0	35.3	0	41.2	0	58.8
D	41.2	52.9	0	5.9	5.9	88.2	0	5.9
E	5.9	52.9	17.6	23.5	0	41.2	5.9	52.9
F	70.6	17.6	5.9	5.9	29.4	29.4	17.6	23.5
G	100	0	0	0	58.8	5.9	11.8	23.5
H	41.2	58.8	0	0	52.9	41.2	5.9	0
I	0	88.2	5.9	5.9	0	35.3	52.9	11.8
J	0	5.9	11.8	82.4	0	0	5.9	94.1

Note: Zero: blank, one: insufficient, two: partially adequate, three: adequate
Source: Authors

Knowledge of functional anatomy related to the planes and axes of movement and types of muscular actions (conceptual classes A and C) significantly increased from the CE program. Knowledge of musculoskeletal anatomy is essential to understand human movement and is a prerequisite to introductory biomechanics courses.

Poor prior knowledge in functional musculoskeletal anatomy in undergraduate students of introductory biomechanics is one of the factors that influence new learning. Students in biomechanics courses often have fragmented, insufficient, or absent prior knowledge about muscle groups and eccentric action[17]. Shigeoka, Bavis, and Seveyka[22] relate the traditional style of teaching anatomy to students' disposition to memorize the content. Rote learning may also be the primary strategy used by anatomy students[23,24] because of the large volume of information and lack of professional context so it is not considered meaningful to human movements by students.

Despite apparent improvement, teachers had difficulties to understand the relation of external forces and joint motion (conceptual class D). This required teachers to think about internal and external forces of the body and their relationship to the required muscle action in movement. For example, in eccentric action, the segment's weight from the force of gravity acts as the cause of movement, while the muscular strength of the antagonist muscle group controls the motion. In classroom interactions, teachers expressed greater ease in understanding movements created by concentric muscle action than that movements were eccentric actions control/brake larger external forces. Similar result was found by Belmont et al[17] when studied undergraduate biomechanics students.

Table 3. Wilcoxon test results comparing the pretest and posttest scores for the biomechanical concept classes identified that are detailed in Table 1

Conceptual classes	Associated Biomechanical Principles[2] Qualitative Diagnosis of Movement-QDM[3]	Z	Observed p
A	Anatomical Principles	-3.1	0.002*
B	Anatomical Principles	0.0	1.000
C	Anatomical Principles/ Force-Motion	-2.4	0.015*
D	Force-Motion/ Balance	-2.4	0.014*
E	Balance	-1.7	0.083
F	Range of Motion	-2.9	0.004*
G	Optimal Projection	-2.4	0.016*
H	Force-Time	-0.3	0.739
I	Diagnosis QDM Phase	-3.2	0.002*
J	Intervention QDM Phase	-1.1	0.257

Note: *Statistically significant change
Source: Authors

Teachers also significantly improved in understanding of the relationship between angular and linear motion concepts (conceptual class F). When the professor showed a picture and discussed the tennis serve, teachers (T) negotiated and shared conceptual meanings[11], helping each other, to understand range of motion principle as can be seen in the following dialog:

> Professor: In what situations do we need movements with much or little range?
> T2: When you want more velocity, you have to increase the range to transfer more velocity to ball.
> T6: There, ball can be velocity, but ... (pointing to the picture).
> T2: There, if he makes the motion very close, he will not be able to transfer velocity to the ball. Then he needs to extend the elbow, move the racket away from the body to perform a wider movement and get more speed. Yesterday I was teaching the serve to a boy in a wheelchair. I gave him a racket and a ball. He started hitting here, like that (demonstrating the movement with little range). I told him to move the racket behind his head to hit the ball. He did the movement exactly because of it. [...].
> T6: It's like in volleyball serve.
> T4: So, if I increase the radius, angular velocity will be increased too.
> Professor: The angular velocity, in this case, will be the same because the angle will not change from here to here (pointing).
> T2: Think of you running on the side of a friend on athletics track. You are at line one and your friend at eight. He'll run a lot more.
> Professor: So, what do we do when we want to throw an implement far away?
> T4: Increasing the radius to linear velocity be faster.
> […]

When the physical education teacher chooses to interact with knowledge and attempted to apply it to a new situation as presented in the dialogue, this represented evidence of meaningful learning[12].

The professor perceived that the optimal projection principle was one that teachers had more easily understood than other biomechanics principles. This evaluation is confirmed by the increase in correct answers related to optimal projection principle (conceptual class G). Stiles and Katene[10] also reported strong improvements in student teachers' answers related to influence to release angle during javelin throw.

Teachers also improved understanding of the essential features of biomechanics applied to evaluating and improving movement technique (conceptual class I). Identifying essential biomechanical features and diagnosing these features in a student's movement is a very important professional skill in physical education. Following instruction teachers were able to better understand movement biomechanics and provide a more accurate diagnosis of technique. A good diagnosis helps teacher to perform the most appropriate intervention which leads to improved movement and lower risk of injury[3].

Conceptual class H did not significantly change because it was not present in the course curriculum[9]. Therefore, students were not expected to advance in knowledge related to Force-Time Principle. The students' answers expressed in this class reinforced the importance of including this principle in future planning for CE courses because teachers' experiences and prior knowledge should be valued in teaching to facilitate meaningful learning[12,18].

Learning of a complex field can be slow, non-linear, and present continuities and discontinuities[25]. This is likely true for biomechanics which involves integration of anatomical, biological, mechanics, and contextual application like physical education. Extensive research using the Biomechanics Concept Inventory has consistently reported that the most influential factors in student mastery of biomechanics concepts are grade point average, student interest in the subject, and their perception of biomechanics application to their future career[26,27]. This complexity and dependence on the meaning attributed by the student to content support the use of meaningful learning theory and active learning pedagogies in biomechanics instruction[28,29]. Given the teachers in this CE program successfully applied the same biomechanical concepts in the course in new situations in testing and qualitative analysis of course discussions, it is possible to affirm that most of the teachers advanced toward meaningful learning of many concepts of biomechanics. These data support the conclusion that the CE program helped teachers to improve mastery and application of biomechanical principles by the physical education teachers in this study.

Teachers' evaluation of the course

The written evaluation of the CE course by the physical education teachers identified positive points, difficulties, and possible areas of improvement. In general, teachers (T) identified more positive feedback than negative (Table 4). A majority (76%) spontaneously reported professor's didactic presentation and interactive discussions were strengths. For instance, T13 said that "the professor was attentive, patient to repeat the explanations, and discussed the content always in a clear and objective way". T4 wrote: "the theoretical basis was good, especially in the epistemological aspect. The organizational and methodological structure of the classes met my expectations".

Thirty-five percent of the teachers believed that classes provided positive reflections about physical education teaching practice. T6 explained that "the course contributed to the daily practice in school physical education, mainly because it made us think about what should be considered in teaching". T9 also affirmed that "my teaching practice, the way I observe, analyze movement, and even planning my classes have been completely modified". These evaluations confirm the importance of well-planned teaching strategies so that teachers acquire pedagogical content knowledge[30,31] and reflect on how to improve their educational practices.

Social interaction with professional peers was another positive point mentioned by 24% of the teachers. T3 said: "I am satisfied to have learned and shared knowledge with colleagues from different education degrees". For T10, "the division in groups, with different students at each class, contributed to the interaction with colleagues which made classes more interesting". According to Hurst, Wallace, and Nixon[1], social interaction can contribute to teachers learning because stimulates problem-solving, critical thinking, learning from others, make learning fun, and become students more interested and engaged. The authors also point out that this kind of learning environment can help teachers to incorporate social interaction in their classrooms. O'Sullivan and Deglau[32] argue that it is important to give teachers, in professional development, time to share ideas and professional experiences that allow them to build and deconstruct their thoughts about physical education and teaching.

Table 4. Categories of physical education teachers' responses to the course evaluation

Categories	Subcategories	Percent
Positive points	Content and professor didactics	76
	Reflection on teaching practice	35
	Social interaction	24
	Covered deficiency in undergraduate biomechanics	18
	Expanded vision about movements and biomechanics	12
	Remember biomechanical content	6
Difficulties	Lack of prior knowledge	12
	Lots of reading for home	6
	Teacher inquiries	6
	Practice-theory logic	6
Suggestions to improvements	Longer course duration	41
	More practical activities	18

Source: Authors

In addition to refreshing biomechanical knowledge and broadening their vision about the application of that knowledge in teaching movement, two teachers said that the courses "supplied deficiencies of biomechanics subjects in undergraduate" (T5) and that "fill the knowledge gap in biomechanics for professional intervention in school physical education" (T4). T14 went further and criticized their undergraduate training in physical education saying that the "undergraduate curriculum of physical education should be reformulated, especially the subjects related to the movement, and there should be a specialization course (360 hours) based on this class".

Although all teachers completed an introductory biomechanics course in their undergraduate degrees, some of them pointed out the lack of prior knowledge in the subject as a factor that made learning more difficult. According to T3, "what made it difficult was the lack of the knowledge about content studied during my undergraduate course". Hsieh *et al.*[27] reported that students' prior domain knowledge can be related to learning biomechanics concepts. This is corroborated by Ausubel[12] who states that the most important factor that influences learning is what students already know.

Other factors reported as difficulties of the CE program were related to pedagogical practice. Teacher T8 believed "there was too much material to be read at home in a short time". In addition, some teachers thought that they would improve mastery in biomechanics if there was more time to study at home and more hours of class devoted to practical activities outside classes (Table 4). At the end of each class, teachers were asked to watch a video or read approximately 15-pages of text for homework. The professor chose short readings because teachers typically do not stop working to attend courses, although this was still perceived as a lot of reading. Brazilian teachers in CE usually report lack of time as a point of difficulty for training[33]. Despite this, Brazilian teachers often seek professional development courses[34].

Furthermore, T5 complained about other teaching strategies, reporting that "the amount of questions asked by the professor to the teachers was great, creating doubts. But there were no immediate answers by the professor. Usually the professor is expected to present content first and then, ask questions and show problems". This teacher likely had not taken part in other courses, explicitly different from traditional lectures. It is not uncommon for some students to resist application questions and other active learning exercises in favor of passive listening and memorization[35-37]. Asking and answering questions is essential for students to establish conceptual relationships, create arguments and develop critical thinking. Appropriate teaching questions help students to remember, understand, apply, analyze, evaluate the phenomena and create alternative hypotheses to solve problems[38].

This study was limited by the small sample of volunteer physical educators from a large city in Brazil and the short course duration. Potential weaknesses included qualitative data reduction by a single investigator and statistical test using a small sample. Despite these limitations, the significant improvement and course evaluations argue for effectiveness of the CE program and opportunities for its improvement.

Conclusion

A CE program based on meaningful learning theory created significant increases in mastery of biomechanical concepts in the Brazilian physical education teachers studied. Both qualitative and quantitative data were consistent with the programs instructional effectiveness predicted by meaningful learning theory. The educators had strong perceptions of the course, peer interaction, and application to professional practice. Difficulties perceived in the course were limited time to study and prior biomechanical knowledge. Other biomechanical concepts and methods for movement analysis can be included and evaluated in future proposals studies such as: dynamometry, electromyography, and ultrasound.

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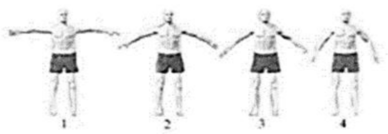
Appendix A

Test questions and corresponding conceptual classes of biomechanical principles examined

Test questions	Classes
1. You are sitting in the bleachers watching a group of students playing volleyball. You observe a student performing the overhand serve but, even after several attempts, the ball does not cross the net.	
a. In your opinion, why the ball did not cross the net?	F*, G, H, I
b. Based on the cause(s) identified by you, what change(s) in the movement performing would you ask student?	J
c. What biomechanical concepts do you identify in this motor skill? Explain each one.	F*
2. Look closely at the figure[39]. Considering only the shoulder joint and that the student is performing the movement very slowly from phase 1 to phase 4, answer: 	
a. The plane and axis of the movement performed.	A
b. The muscular group(s) responsible for this movement.	B
c. Identify the type of muscle action performed.	C
d. Identify the force(s) that acts (or act) as resistance to do the movement.	D
3. Considering that the figures below are made of the same material and have hat homogeneous distribution, mark with a dot the center of mass location of each object. 	E

Note: * Category F was counted only once from analysis of responses 1a and 1c