CONCEPTUAL FIELDS THEORY AS A TOOL FOR PLANNING AND BUILDING TECHNOLOGICAL RESOURCES FOR SCIENCE EDUCATION

TEORIA DOS CAMPOS CONCEITUAIS COMO INSTRUMENTO PARA O PLANEJAMENTO E CONSTRUÇÃO DE RECURSOS TECNOLÓGICOS PARA O ENSINO DE CIÊNCIAS

TEORÍA DE LOS CAMPOS CONCEPTUALES COMO INSTRUMENTO PARA PLANIFICACIÓN Y CONSTRUCCIÓN DE RECURSOS TECNOLÓGICOS PARA LA ENSEÑANZA DE CIENCIAS

Priscila Cadorin NICOLETE[1]
Aline Coelho dos SANTOS[2]
Liane Margarida Rockenbach TAROUCO[3]
Marta Adriana Machado da SILVA[4]

ABSTRACT: This research examines the role of technological resources in lesson planning and teaching practices in the context of Vergnaud's Theory of Conceptual Fields. All the work on the lectures was carried out using App Inventor to create a mobile app for 9th Grade students (age 13-14). Students had to understand how the mobile application contributes to learning Archimedes' principle and then take part on a survey after been given the lecture on buoyant force. The survey was taken by 78 students from a public school, with a quantitative and qualitative approach to the case study. Following this, the analysis showed that the Theory of Conceptual Fields is a crucial reference of didactic planning and can be used to build technological resources that actively engage students throughout their learning process, because it supports the class environment in selecting concepts and key-theories and what correlates between them.

KEYWORDS: Theory of conceptual fields. Science teaching. Mobile learning.

RESUMO*: Este trabalho apresenta a Teoria dos Campos Conceituais de Vergnaud como instrumento para o planejamento e construção de recursos tecnológicos para práticas pedagógicas. O estudo tem como objetivo investigar de que maneira um aplicativo móvel, à*

[1] Federal University of Rio Grande do Sul (UFRGS), Porto Alegre – RS – Brazil. Doctoral student in the Postgraduate Program in Informatics in Education, Interdisciplinary Center for New Technologies in Education. Scholarship from the National Council for Scientific and Technological Development (CNPq). ORCID: https://orcid.org/0000-0002-4185-6417. E-mail: priscilanicolete@hotmail.com
[2] Murialdo High School, Araranguá – SC – Brazil. Teacher of Basic Education in the Department of Natural Sciences. Master's in Information and Communication Technologies (UFSC). ORCID: https://orcid.org/0000-0002-0931-2372. E-mail: aline.cds@live.com
[3] Federal University of Rio Grande do Sul (UFRGS), Porto Alegre – RS – Brazil. Professor at the Interdisciplinary Center for New Technologies in Education. Doctorate in Electrical Engineering (USP). ORCID: https://orcid.org/0000-0002-5669-588X. E-mail: liane@penta.ufrgs.br
[4] University of the Extreme South of Santa Catarina (UNESC), Criciúma – SC – Brazil. Professor in the Distance Education Sector. Doctorate in Engineering and Knowledge Management (UFSC). ORCID: https://orcid.org/0000-0002-0002-9781. E-mail: marta.php@gmail.com

luz da teoria de Vergnaud, pode contribuir para o ensino de conceitos referentes ao Princípio de Arquimedes para alunos do 9º ano do ensino fundamental. A pesquisa foi realizada com 78 estudantes de uma escola pública e teve uma abordagem quantitativa e qualitativa, com procedimento de um estudo de caso. O estudo demonstra o potencial da teoria de Vergnaud como referencial teórico para o planejamento didático e na construção de recursos tecnológicos que envolvam ativamente os estudantes nos processos de ensino e aprendizagem, pois auxilia no desenho de situações de ensino, na seleção dos conceitos e teoremas-chave e suas relações.

***PALAVRAS-CHAVE**: Teoria dos campos conceituais. Ensino de ciências. Aprendizagem móvel.*

***RESUMEN**: Este trabajo presenta la Teoría de los Campos Conceptuales de Vergnaud como un instrumento para planificación y construcción de recursos tecnológicos para prácticas pedagógicas. El estudio tiene como objetivo investigar de qué manera un aplicativo móvil a la luz de la teoría de Vergnaud puede contribuir a la enseñanza de conceptos relacionados con el Principio de Arquímedes para estudiantes en el noveno grado de la escuela primaria. La investigación se llevó a cabo con 78 estudiantes de una escuela primaria pública y tuvo un enfoque cuantitativo y cualitativo, con el procedimiento de un estudio de caso. El estudio demuestra el potencial de la teoría de Vergnaud como marco teórico para la planificación didáctica y la construcción de recursos tecnológicos que involucran activamente a los estudiantes en los procesos de enseñanza y aprendizaje, ya que ayuda en el diseño de situaciones de enseñanza, en la selección de conceptos y teoremas clave y las relaciones entre ellas.*

***PALABRAS CLAVE**: Teoría de los campos conceptuales. Enseñanza de Ciencias. Aprendizaje móvil.*

Introduction

The study exposed here presents the use of the Theory of Conceptual Fields as a theoretical framework for the construction of a mobile application (app) for teaching the "Principle of Archimedes". To understand this content, the student needs to understand concepts such as density and buoyancy. The application was inspired by the experiment developed by Jean Piaget and Bärbel Inhelder, which can be found in the book From the child's logic to the adolescent's logic (1976). This experiment consists of making objects of different sizes and materials available for the subject to classify, indicating which objects float and which sink in water, in addition to justifying the reasons for their classification. Next, the subject must deposit the objects in a water tank and observe the behavior of each object. At the end, he must summarize his results in order to arrive at a law (PIAGET; INHELDER, 1976).

The studies by Piaget *et al.* were not aimed at building school knowledge, but at the process of cognitive development (NOGUEIRA; REZENDE, 2014). However, Piagetian assumptions were crucial for the elaboration of Gérard Vergnaud's Theory of Conceptual Fields, which favor intervention practices for the classroom. Thus, Piaget and Inhelder's experiment was used as an inspiration for the creation of the app, which however was built in the light of Vergnaud's Theory of Conceptual Fields, with the objective of intervening in the teaching and learning process, offering subsidies to the student to reach the knowledge.

The App Inventor platform (https://appinventor.mit.edu/explore) created by the Massachusetts Institute of Technology (MIT) was used to develop the application. The MIT platform was chosen because it is a visual and intuitive programming environment, designed to allow anyone to create fully functional applications for smartphones and tablets (MIT, 2020).

Thus, this study has the following research question: *How can a mobile application, developed in the light of the Theory of Conceptual Fields, contribute to the teaching and learning processes of concepts related to Archimedes' Principle?* To answer, the study followed a qualitative and quantitative approach, with technical procedures of a case study.

Conceptual Fields Theory

The Theory of Conceptual Fields (TCF), developed by Gérnard Vergnaud, is a cognitive theory that aims to "propose a structure that allows understanding the affiliations and ruptures between knowledge, in children and adolescents" (VERGNAUD, 1993, our translation). Theory provides a theoretical framework for investigations into complex cognitive activities, especially those related to scientific and technical learning.

The focus of theory is on representations, schemes and concepts used by students to solve problems. For Vergnaud, the teaching of a concept cannot be reduced to its definition, as a concept will only be understood by the individual if it is applied in situations, as well as in problem solving that will make sense of it. (FIOREZE *et al.,* 2013).

Vergnaud argues that obtaining knowledge follows three essential premises: *(1) a concept is not formed from a single type of situation,* in this way, the researcher suggests the need to diversify teaching activities, in order to allow students the possibility of testing their explanatory models in different contexts, enriching such models or transforming them; *(2) a situation is not analyzed with a single concept*, which implies the need for an integrative vision of knowledge, and; *(3) the construction and appropriation of all properties of a* *concept or all aspects of a situation is a long process.* (DE CARVALHO JÚNIOR; DE AGUIAR JUNIOR, 2008; VERGNAUD, 1993).

As can be seen, in TCF, Vergnaud emphasizes that cognitive development depends on specific situations and conceptualizations necessary to deal with them (DE CARVALHO JÚNIOR; DE AGUIAR JUNIOR, 2008; MOREIRA, 2002). The author states that knowledge is formed from problems and situations to be resolved. These situations are tasks to be performed by the subject, which can be theoretical or practical, in which he will need to discover relationships, make inferences, develop hypotheses and produce a solution.

> Let's look at some examples: buying gifts, fruits or bonbons; set the table; personal accounts; seats at the table; play marbles. All of these, for a 6-year-old child, are activities favorable to the development of mathematical conceptualizations related to number, comparison, addition and subtraction. (VERGNAUD, 1993, our translation).

The theorist highlights the construction and use of schemas as one of the main elements for learning (MOREIRA, 2002), defining them as "[...] the invariant organization of behavior for a given class of situations" (VERGNAUD, 1993, p. 2, our translation). Vergnaud emphasizes that it is in the schemas that the subject's knowledge-in-action must be researched, that is, the cognitive elements that make the subject's action operative. Thus, it is through the construction of a broad repertoire of schemes that cognitive development takes place, as it is through these schemes that the subject will be able to master different situations that are presented to him.

Thus, a scheme is composed of four basic elements: (a) *goals and anticipations*, from which the subject can discover a possible purpose; (b) *action rules* of the "if...then" type, that is, rules for the generation of the schema, they are rules for seeking information and controlling the results, allowing the subject to create the sequence of actions; (c) *operative invariants*, are the knowledge contained in the schemas, which constitute the basis and allow the subject to obtain pertinent information. It is through them that the subject makes inferences, sets goals and defines his actions, and finally; (d) *inference*, which allows the subject to reason to make decisions in view of the situation and from the information of the previous elements (NOGUEIRA; REZENDE, 2014; ROCHA; BASSO, 2017).

Thus, for Vergnaud, a concept is formed by three elements: the set of situations that give meaning to the concept; the invariants that represent the meaning of the concept, and; the symbolic representations that allow symbolic representation of the concept (VERGNAUD, 1993).

Materials and methods

This article is based on the presentation of Vergnaud's TCF as an instrument for the planning, construction and application of technological resources for pedagogical practices in the classroom, and on the understanding of the possible benefits generated for the teaching and learning processes. Thus, the study is characterized as explanatory and with a mixed approach, using quantitative and qualitative techniques in order to describe the causes of a phenomenon. To carry out this research, the following steps were necessary: (i) study of the Theory of Conceptual Fields; (ii) study of the experiment "Floats or Sinks?" by Piaget and Inhelder (1976); (iii) interview with the Science teacher; (iv) study of the App Inventor platform; (v) construction of the mobile application; (vi) application of the class on Archimedes' principle using the developed app; (vii) data collection and analysis.

Application in the classroom was preceded by a diagnostic assessment and ended with a conceptual assessment. These assessments had the same content, consisting of 12 questions about concepts related to Archimedes' principle. This test is part of the data collection instruments and aimed to verify the evolution of students in relation to the studied content. With the same objective, at the end, the students still needed to write a report about what they had learned.

In addition, after all activities were completed, a questionnaire was applied to learn about the students' perceptions about the activities carried out using the app, from the point of view of the ICT context. For this, a 10-question questionnaire developed by Favier and van der Schee (2012) and 7 questions taken from the questionnaire developed by Heck (2017) were used, resulting in a questionnaire of 17 questions arranged on a five-point Likert scale. The questions correspond to five dimensions: implementation, with the objective of verifying the ease of use, design and instructions for use; content, relevance of displayed information; satisfaction, identifying how much students enjoyed using the app; hardware, knowing the students' confidence when using smartphones to learn; and finally, implementation and content. In addition, the questionnaire has an open question in which the student could indicate positive and negative points of the app used.

The study sample corresponds to 80 students from 3 classes of the Municipal School of Elementary School Paquetá in the city of Brusque – Santa Catarina, of which 78 performed all the proposed activities.

The app "Floats or Sinks?"

The mobile app called “Floats or Sinks?” explores concepts such as Density and Buoyancy through the use of experimentation, videos, questioning and writing activity. Situations, operative invariants and symbolic representations of the concepts were identified, as defined by Vergnaud (Table 1).

Table 1 – Situations, operative invariants and symbolic representation of Archimedes' Principle

Situations involving the concepts of Buoyancy and Density		Operative invariants capable of being enunciated by students	symbolic representations
Objects that float or sink in water. Operating system of a ship.		The density of a body that determines whether it will float or sink in fluid. The body sinks if the density of the body is greater than the density of the fluid; The body is in equilibrium if the density of the body is equal to the density of the fluid; The body floats on the surface if the body density is less fluid density. Buoyancy is the force that the liquid acts on the body that is immersed or partially immersed. Volume of liquid displaced is equal to the Volume of the body that is in equilibrium.	$d = \frac{m}{v}$ • d = density (kg/m³) • m = mass (g) • v = volume (m³) $\overline{E} = d_F \cdot V_{FD} \cdot g$ • $\vec{E}$ = buoyancy (N) • d_F = fluid density (kg/m³) • V_{FD} = fluid volume displaced (m³) • g = gravity acceleration (m/s²)

Source: Devised by the authors

Thus, the application aims to instigate students' curiosity with experiments, images and videos that explore the content. The application was designed in the form of a Didactic Sequence, in order to offer the student different moments of learning. It begins with Piaget and Inhelder's experiment, with the aim of sharpening the students' curiosity, and then, as it progresses to the next screens, the concepts are progressively introduced (Figure 1).

Figure 1 – “Floats or Sinks?” application screens

Source: Play Store – Archimedes' Principle App - “Flutua ou Afunda?”

The first screen contains different objects, under which the student must decide whether they sink or float in water; when making their choice, the student must inform the reasons for their classification. This experimentation in the tank intends to provide a moment of reflection on their conceptions in relation to the theme. Reflections can lead to answers such as: *“The object sinks because it is heavy”* or *“it floats because it's small”,* however, through experimentation he can see that, for example, a “small” and “light” coin will not float. Here, the intention is to destabilize conceptions that until then were stable so that a new arrangement can be built, thus generating advances in the students' conceptual understanding.

That is, the student will test their schemes, and if they are ineffective for that situation, the experience will make them change schemes or modify their schemes (ROCHA; BASSO, 2017). In this sense, this experimentation aims to destabilize operative invariants, providing opportunities for learning.

Student responses are stored in a database, in order to be later analyzed by the teacher, so the teacher can identify which initial schemes used by students. These schemes must be considered as precursors of scientific concepts to be acquired. According to Moreira (2002), it is necessary to identify which prior knowledge the child can rely on and which ruptures are necessary for the construction of knowledge.

After the student finishes his experiment, he is taken to a new screen. At this point, the concepts of density and buoyancy are introduced, through the question “*Why doesn't the boat sink?*”, then a video is shown. Thus, the objective is that the construction of knowledge takes place through a situation that gives meaning to the concept. Through experimentation and questioning, an attempt is made to build situations to help students discover relationships, make inferences and develop hypotheses.

With initial ideas about the concepts, the student is redirected to a new screen, where he is invited to perform the experiment in the tank again with new objects. As mentioned before, for Vergnaud a concept is not formed from a single type of situation, thus, here, the objective was to diversify the teaching situations, in order to allow students the possibility to test their new knowledge.

In the last two screens, the subject is deepened, detailing and formalizing the concepts with symbolic expressions. Screen 4 presents information on the way in which Archimedes developed his theory and a summary of the concept of buoyancy, relating it to icebergs and ships; this is done through images and texts. Finally, on screen 5, the concepts are formalized with a video and, at the end, the student must write a report on what he learned.

Technical details of application development on the App Inventor platform can be found in Nicolete, Tarouco and dos Santos (2018).

Planning and applying in the classroom

The applications of the activities were carried out in science classes, in 3 9th grade groups in a Municipal Elementary School, in the city of Brusque, SC. The development of classes and exploration of the app took place as specified in the lesson plan (Table 2).

Table 2 – Class plan

IDENTIFICATION	
Curriculum Component: Science	Target Audience: 9th grade Elementary School
Class Topic: Buoyancy	Thematic unit: Force and Movement
Knowledge Objects: Concept of strength; Resultant strength; Fundamental principle of dynamics; Strength weight; Inertia principle; Principle of action and reaction; Principle of Archimedes.	
Competence: To question and understand natural and technological processes, the language of science, its evolution and social implications of scientific and technological knowledge.	
Ability: Understand scientific concepts present in our daily lives such as strength, density and buoyance, through practical and virtual experiments, developing the ability to question and investigate these phenomena, developing solutions aimed at developing the proposed activities.	
Duration: 2 weeks (6 in-person lessons)	
DIFFICULTIES PRESENTED BY THE CLASS	
(1) The class in question has low academic performance in knowledge relevant to physics, which involve logical mathematical reasoning. (2) Because they are having their first contact with physics, students feel insecure and believe that the contents are too complex. (3) Most students have difficulty relating theory to practice, necessary and pertinent knowledge in our daily lives.	
METHODOLOGICAL PROCEDURES	
The class in question adopts methodological procedures characteristic of a hybrid teaching, making use of different resources and methods capable of meeting the diversity of learning profiles that we find in a classroom. In this sense, it adopts a constructivist approach, with the entire teaching process centered on the student, valuing their autonomous and active profile. The development of classes for this content adopts an	

investigative approach and relies on the following learning strategies: (i) Diagnostic assessment to identify prior knowledge; (ii) Use of the “Sink or Float?” application; (iii) Carrying out research activities; (iv) Preparation of a Virtual Experimentation Report; (v) Conceptual Assessment.		
JUSTIFICATION OF THE METHODOLOGICAL PROPOSAL		
Investigative teaching proposals are being strongly associated with the integration of educational technologies, especially regarding the promotion of Science Teaching, which is most responsible for the development of scientific and technological knowledge that drives the economy of a society (GÜTL *et al*., 2012).		
RESOURCES		
Mobile devices (smatphones), Internet and school space (classroom, for example)		
Stages	Duration	PLANNED ACTIVITY
1	1 lesson 45 min	➲ Diagnostic assessment: Students will be given an assessment with objective questions, on the themes explored, to identify prior knowledge.
2	2 lessons 90 min	➲ Use of the “Floats or sinks?” application: Students experiment, observe and raise hypotheses about a simulator. Therefore, they are addressed to a problem question about the operation of ships. The concepts that involve this theme are deepened with short texts, animations and videos. Finally, the student will need to test their hypotheses, now with more solid knowledge.
3	1 lesson 45 Min	➲ Preparation of Experimental Report (activity performed in the application)
4	2 lessons 90 Min	➲ Conceptual assessment: In this phase, conceptual assessment is applied to students, exploring the concepts learned. ➲ Tool Assessment: At this point, students will be given an assessment regarding the “Floats or sinks?” application.
ASSESSMENT		
The evaluation of the explored knowledge will be given by the proposed activities: (a) evaluation 1: Experimentation Report; (b) evaluation 2: Conceptual Assessment.		

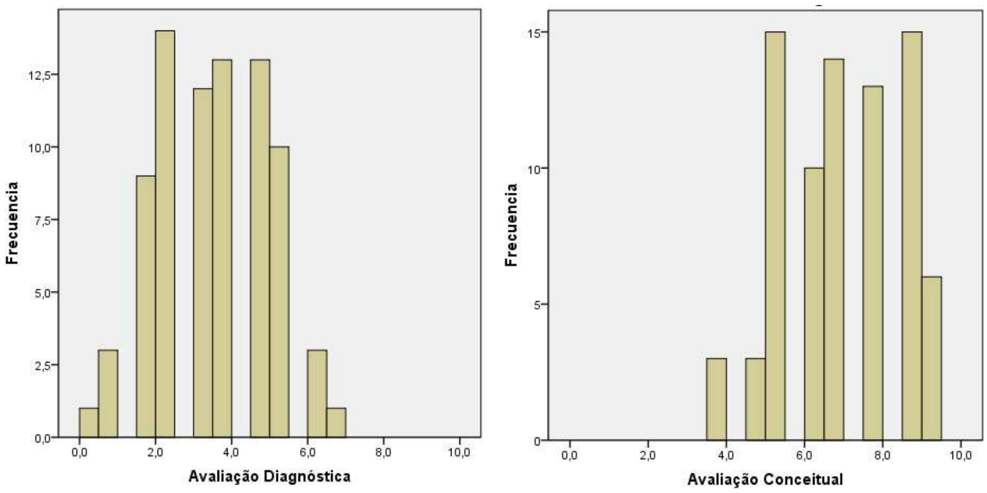
Source: Devised by the authors

Results

Based on the results presented by the students, under evaluation, it was possible to draw an overall average of student achievement. The initial average for the Diagnostic Assessment (DA) was 3.47 (standard deviation of 1.51), while in the Conceptual Assessment (CA) students had an average of 6.93 (standard deviation of 1.44). Statistically, it can be said that the result obtained was significant, since, applying the Student's t-test, we have $p = 0.000$ ($\alpha = 0.05$).

Still, it is possible, through the histogram (Figure 2), to identify the most frequent notes, presented at first in DA, and in a second moment, in CA. It is noticed that the most frequent achievement in the first assessment is between 2.0 - 5.0, the most evident in this sample, while in the conceptual assessment, the highest grades stand out, which demonstrates the progression of most students towards the proposed activity.

Figure 2 – Histogram referring to the absolute frequency of student earnings in DA and CA



Source: Devised by the authors

It is also noted that all classes showed progression of knowledge after classes using the application. Applying the Student's t Test to each class individually, using information from diagnostic assessment and conceptual assessment, it can be seen that, statistically, all classes obtained a satisfactory final learning index, obtaining $p = 0.000$, demonstrating that there was a difference between the diagnostic and conceptual assessments (Table 3).

As can be seen in Table 3, classes A and B showed an increase in relation to the initial (DA) and final (CA) assessment of 3.18 and 3.04 points, respectively. Class C, on the other hand, had the biggest difference between the assessments, which was 4.16. This evidence is mainly due to the involvement of the class at the time of application, in which the students were more focused, and they repeated the proposed activities several times, reviewing the videos and reexploring the simulator. In addition, students reported that they used the "Floats and Sinks" app extra-class in their homes.

Table 3 – Student t test averages and values for each class

Classes	μ DA	DA standard deviation	μ CA	CA standard deviation	Value of t	Value of p
Class A	3.33	1.28	6.51	1.42	7.20	0.00
Class B	3.67	1.31	6.74	1.42	9.69	0.00
Class C	3.37	1.89	7.53	1.33	10.68	0.00

5% significance level ($\alpha = 0.05$)
Source: Devised by the authors

The pre-test and the first experiment in the tank were intended – in addition to helping the teacher to understand the students' initial schemes – to provide students with a moment of reflection on their conceptions of the topic and to destabilize the possible false operative invariants. Through the pre-test, it can be seen that the false operative invariants most mobilized by the students were:

- Objects sink because they are heavy (they associated the fact that objects sink or float with their mass);
- That the Buoyancy force could only be applied to liquids;
- That icebergs were trapped and fixed to the bottom of the sea;
- That the ship floated because it was less heavy than the water that supported it.

The tank experiment revealed that the students' initial beliefs about objects floating or sinking in water were related, in particular, to whether the object was light or heavy (Figure 3). However, the words material and water also stood out, which are related to the sentences: "*Because of the material it is made of*", "*Because it is heavier than water*" and "*Because it is lighter than water*", which shows that some students were already able to identify that justifications such as "the object is light or heavy" were not enough to resolve the situation.

Figure 3 – Most frequent words among answers in the first tank experiment

Source: Devised by the authors

At the end of classes, using the app, the student should write a short report about what he learned, with this it was possible to perceive the evolution of knowledge and, consequently, the construction of new operating invariants on the subject. Of the 78 students, 66 responded. Table 5 presents each operative invariant that can be stated on the topic and the main responses of the students. Some reports are presented that represent the responses of most students who participated in the survey.

Table 4 – Operative invariant that can be stated and student responses

The density of a body that determines whether it will float or sink in fluid. A1. I learned that there are some materials that float or sink because of the material it is made [...] it is not the mass that determines whether the body sinks or floats, [...] the density of the body is less than the density of the liquid, for example us, our density is less than the density of the liquid, that's why we float. A5. It floats or sinks because of its density which is the ratio between mass and volume. A10. It is not the mass that determines whether a body floats or sinks, but the density. If the body is denser than the liquid it will sink, if it is less dense it will float.
The body sinks if the density of the body is greater than the density of the fluid. A1. Why does a small stone sink? because it is denser than liquid. A body denser than liquid sinks. A7. Body sinks: The density of the body is GREATER than the density of the liquid.
The body is in equilibrium if the density of the body is equal to the density of the fluid. A7. Body is immersed in balance: The density of the body is exactly EQUAL the density of the liquid. A10. Body is immersed but in balance: The density of the body is exactly the same as the density of the liquid and the weight is equal to the buoyancy
The body floats on the surface if the body density is less fluid density. A1. Since a boat is less dense than the water it will float A4. All I could understand was that a ship does not sink because a ship is lighter than water [...]. The buoyancy and the iceberg have to do with each other because the ice on the iceberg is formed by polar ice that is, formed by freshwater ice which has less density.. A10. Floating body: Density of the body is less than the density of the liquid.
Buoyancy is the force with which the liquid acts on the body that is immersed or partially immersed. A3. Buoyancy is a name given to the force exerted by a fluid on an object totally or practically immersed in it, also known as Archimedes' Principle, and buoyancy always has a vertical direction and upwards in the appearance of a vertical force upwards, buoyancy does not arise only in liquid for example a balloon floats because atmospheric air which is a fluid exerts a force on it greater than its weight. A4. The buoyancy theory is that every body that is immersed in a pool, bathtub etc... tends to have an upward vertical force, the intensity of which is equal to the fluid weight of the body [...]. A16. The buoyancy or Archimedes principle is the weight of the volume of liquid displaced, it is a force, so its unit of measure is Newton, it always has a vertical direction and an upward direction.
Volume of displaced liquid equals the Volume of the body the body that is in equilibrium A5. The more water the ship is able to displace, the greater will be the reaction of the water with the ship, and this all depends on the density of the water. A16. A huge and heavy ship does not sink because the weight of the ship displaces a certain volume of water and provokes a reaction in the opposite direction [...]. A17. Ships DO NOT sink because the weight of the boat displaces a certain volume of water and causes a reaction in the opposite direction.

Source: Devised by the authors

It was also possible to notice that the way the topic was approached in the application piqued the students' curiosity, mainly for having taken the topic to real everyday situations. This can be evidenced by the many reports that addressed the operation of ships and icebergs:

> *[...] If the water pushes the ship upwards, it will not tip over, as inside a ship's hull there are several water chambers that prevent the ship from turning. Who controls the amount of water that goes into these cabins, is the captain, who monitors everything from his cabin, on the outside of the ship's hull there is a series of measures called plimsoll (A16).*
>
> *Icebergs are chunks of ice that float in icy waters. They are made up of fresh water, only 10% of which emerges on the surface. Icebergs only float because fresh water is less dense than salt water, thus suffering greater pressure. (A7).*

Regarding the second part of the data collection, which aimed to understand the students' perceptions about the activities carried out from the point of view of the ICT context, the students' perceptions were analyzed in five different dimensions: implementation aspects, content, tool satisfaction, hardware and content-implementation. It can be seen that, in general, the students obtained a good acceptance of the approach used. The answers had a mode value between 4 and 5 ("4. Partially Agree" (CP) and "5. Totally Agree" (CT)) for the positive affirmatives and 1 and 2 ("2. Partially disagree" (CP) and “5. Strongly Disagree”) for negative statements (Table 5).

Table 5 – Students' perceptions when using the “Floats or Sinks?” application in class

	Questions	DT	DP	SO	CP	CT	Total
Implementation	Q1. I was not comfortable using the app.	56 (72%)	7 (9%)	5 (6%)	1 (1%)	9 (12%)	78(100 %)
	Q3. It was easy to navigate the "Floats or Sinks?"	2 (3%)	9 (12%)	5 (6%)	15 (19%)	47 (60%)	78(100 %)
	Q7. The application's graphic design is not visually appealing	16 (21%)	16 (21%)	17 (22%)	23 (29%)	6 (8%)	78(100 %)
	Q8. It was difficult to use the app.	50 (64%)	8 (10%)	7 (9%)	4 (5%)	9 (12%)	78(100 %)
	Q9. I received enough information to use the app.	1 (1%)	3 (4%)	10 (13%)	18 (23%)	46 (59%)	78(100 %)
	Q16. It was simple to use the “Floats of Sinks” application.	2 (3%)	3 (4%)	5 (6%)	16 (21%)	52 (67%)	78(100 %)
	Q17. I didn't find any problems to perform the actions I wanted in the application.	5 (6%)	4 (5%)	6 (8%)	23 (29%)	40 (51%)	78(100 %)
Conteúdo	Q4. The information displayed in the app was not always accurate.	43 (55%)	19 (24%)	10 (13%)	4 (5%)	2 (3%)	78(100 %)
	Q5. The app offered enough information about the studied content.	2 (3%)	2 (3%)	8 (10%)	20 (26%)	46 (59%)	78(100 %)
	Q10. I liked the way the information was presented in the app.	2 (3%)	2 (3%)	8 (10%)	15 (19%)	51 (65%)	78(100 %)
I n C	Q6. The app offered important information for my learning.	1 (1%)	1 (1%)	3 (4%)	8 (10%)	65 (83%)	78(100 %)
Satisfaction	Q11. Overall, I'm satisfied with the “sinks or floats” application.	1 (1%)	3 (4%)	7 (9%)	17 (22%)	50 (64%)	78(100 %)
	Q12. Using a cell phone (Smartphone) increased my motivation to learn physics.	1 (1%)	1 (1%)	8 (10%)	12 (15%)	56 (72%)	78(100 %)
	Q13. I would like to use other applications in the physics discipline.	0 (0%)	0 (0%)	6 (8%)	3 (4%)	69 (88%)	78(100 %)
	Q14. I would advise my friends to use the “Floats or Sinks” application.	0 (0%)	0 (0%)	4 (5%)	15 (19%)	59 (76%)	78(100 %)
	Q15. The “Floats or Sinks” app was relevant to my studies.	1 (1%)	0 (0%)	7 (9%)	14 (18%)	56 (72%)	78(100 %)
Hard	Q2. I was confident in using the app on Smartphone (mobile phone).	2 (3%)	3 (4%)	7 (9%)	13 (17%)	53 (68%)	78(100 %)

Source: Devised by the authors

This positive attitude can also be found among the reports of students in the open question, in which they needed to indicate positive and negative points about using the app in class. Below are some of these responses:

> *I had no problems with the app, it was super easy to use, it was a different and cool class, I really liked it. I have nothing to complain about, it's not heavy and it didn't crash. It's great to use a cell phone at school, faster and more convenient. No need to copy material from the whiteboard. I loved it! (A4)*

> *The class was very interesting, as we use cell phones as a learning and study material. I was able to better understand the matter using the app. And I think that if we use cell phones and applications more often as a form of study, it could end up drawing more attention and curiosity from many students. (A33).*

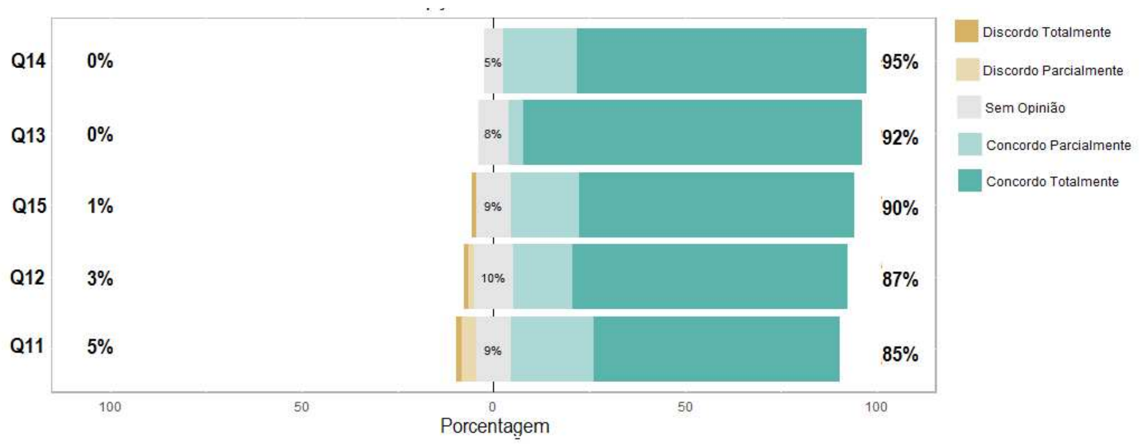
Performing a separate analysis by dimension, it is evident that the perception of students in relation to their satisfaction in using the application showed better agreement rates when compared to other dimensions (Figure 4). The question "*Q13. I would like to use other applications in the discipline of physics*", which obtained 92% agreement, corroborating the report of some students:

> *The app helped me learn more about the topic and made me more interested in physics. But I would like this application not only to be used in physics classes, but for all subjects. Because the student can use it more in the classroom and also Distance Education anywhere (A17).*

> *I thought the app was really cool, a way to use technology for learning and not just to pass the time. I would suggest it to other teachers. We were much more efficient than in normal classes (A18).*

Likewise, the questions "*Q14. I would advise my friends to use the "Floats or Sinks"*" application, with a total and partial agreement rate of 76% and 19%, respectively, and; "*Q15. The app "Floats or Sinks" was relevant to my studies*", of which 72% of the students totally agreed and 18% partially agreed with the students' satisfaction in using the app in class.

Figure 4 – Students' perceptions of their satisfaction in using the Floats or Sinks app?



Source: Devised by the authors Elaborado pelas autoras

Complementing question Q15, the question "*Q6" stands out. The application offered important information for my learning*", of the implementation-content dimension ("I and C" in table 5), with a total agreement rate of 83% and 10% partial agreement. Likewise, the *content* dimension, in general, showed positive indices, which demonstrates a good acceptance of students in relation to the content presented and their learning using the application. These data are reaffirmed through the students' reports:

> *The app for me was really good to use. I felt more prepared because of the information that was in it. The information was very complete (A16)*
>
> *[..] the app is really rich in information and knowledge. I believe that its use made the class more practical and productive [...] (A35).*

The implementation dimension, in order to verify the ease of use, design and instructions for use, had the lowest acceptance rates, highlighting the question "*Q7. The application's graphic designer is not visually attractive*", which achieved a 37% agreement rate. This perception can be evidenced in reports from students, who suggested improvements in the application's design:

> *I thought it was really cool to be able to use the cell phone in class, as the cell phone is something that is very present in our daily lives and consequently holds us back more. When we were using it, everyone really did the activities and dedicated themselves. It could improve the design. I liked using the app because it made the class more dynamic and attractive to the eyes of the students. (A21).*
>
> *The app itself is quite interesting. When I downloaded the app I imagined something with text and questions, but the game was a very interesting and efficient way to work on the buoyant subject. I really like the way the app*

> *approached, the subject, as the explanations is a great complement. The designer needs to improve, but with the app I'm very satisfied. (A31).*

It is noteworthy that, despite the students suggesting improvements in the application's design, most students reported that they had no problems learning to use the application, describing it as being easy to use, as shown in questions Q3 and Q9 (Table 5). Another point to highlight in this dimension is in relation to the school's internet: some students reported difficulties in running the application, such as crashing and slowness, and they associated this with the poor quality internet offered by the institution. As the database used in the application is hosted in the cloud, these difficulties can really be associated with the internet, however, it is important to note that the application has many images, which requires the device's processor and can lead to slow execution.

Final considerations

This study shows that the use of the mobile application positively contributed to the teaching of concepts related to Archimedes' principle, when planned within the principles presented in the Theory of Conceptual Fields.

The theory stands out for the attention and importance with which Vergnaud treats the subject-in-situation. This point brought elucidation in the construction of activities provided for in the lesson plan, in the development of the "Floats or Sinks" app and in the analysis of teaching and learning situations, when concepts were worked on within Archimedes' Principle, as Vergnaud's theory brings the need to accompany students throughout the learning process, seeking to identify the temporal progression of their knowledge in the concepts and theorems in action.

It is noteworthy that the theory of conceptual fields allowed the teacher to think about their teaching object in a more global way, working better on the concepts covered, the level of depth of the proposed activities and the evaluation: it is understood that these situations should be planned from the selection of situations that should be faced by students.

The results also point to a great satisfaction among students regarding the use of smartphones in the classroom, and the way in which this resource increased their interest and motivation for the content being worked on. Therefore, the practice proposed as an object of study in this research presents itself as a promising theoretical framework for research that wants to focus on the subject in action, involved in an active learning process, while intending to make use of mobile learning.

In summary, the study demonstrates the potential of Vergnaud's theory as a theoretical framework for didactic planning and construction of technological resources that actively involve students in teaching and learning processes. Theory helped in the design of teaching situations, in the selection of key concepts and theorems and their relationships. Presenting itself, integrated with technological resources, as an innovative teaching proposal with high acceptance and usability by students.

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How to reference this article

NICOLETE, P. C.; SANTOS, A. C.; TAROUCO, L. M. R.; SILVA, M. A. M. Conceptual fields theory as a tool for planning and building technological resources for science education. **Revista Ibero-Americana de Estudos em Educação**, Araraquara, v. 16, n. 4, p. 2551-2568, Oct./Dec. 2021. e-ISSN: 1982-5587. DOI: https://doi.org/10.21723/riaee.v16i4.13435

Submitted: 17/07/2021
Required revisions: 21/08/2021
Approved: 20/09/2021
Published: 21/10/2021