

# Cardiac Cycle Puzzle: Development and Analysis of Students' Perception of an Online Digital Version for Teaching Cardiac Physiology

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## Abstract

Cardiac physiology is a basic subject in the curriculum of health Science undergraduate courses, which allow students to understand the functional mechanisms of cardiovascular organs as well as the physiopathology of cardiovascular diseases. The puzzle of cardiac cycle has been developed to help students to understand and integrate the concepts of morphology and physiology of normal and pathological states of the heart. Considering the good acceptance of the printed puzzle by students and professors, its online version has been developed as a digital educational tool. The aims of this work were to describe the development of the online digital version of this educational game and to evaluate the students' perception of the utility of the digital game for their learning. The digital version was developed using the figures and answers of the original printed cardiac cycle puzzle, including stages 1 and 2, in three languages: Portuguese, English and Spanish. The digital version was tested by professors of Physiology from different university institutions for validation. The final version of game was used in remote teaching in three courses in the health area, during the COVID-19 pandemic. The opinion of students about the usefulness of the game activity for their learning was analyzed by using a survey. In the opinion of participants in this study, the activity with the online digital version of the cardiac cycle puzzle was useful for their learning.

**Keywords:** *Serious game, Active teaching method, Puzzle, Cardiac cycle, Student perception*

## 1 Introduction

Cardiovascular physiology is an important and complex issue in the health courses curriculum. Professionals of health career must know the morpho-functional characteristics of the cardiovascular system, in order to understand the physiopathological changes of the heart and blood vessels, as well as integrate basic knowledge and clinical application. As a result, the professional will be able to guide, to diagnose and to treat cardiovascular diseases (Abreu *et al.* 2014; Azer, 2014; Malta *et al.* 2014).

First and second-year students of healthcare careers struggle to integrate cardiac morphological and physiological concepts. And it becomes more challenging when the teaching-learning process is fractioned into subjects and based on the transmission and memorization of content in a professor-centered model (Borges *et al.* 2016). For meaningful learning to occur, it is necessary to be student-centered process, using active teaching strategies like educational games (Tarouco *et al.* 2004; Berbel, 2011).

The learning-process "is facilitated when it is done in a fun activity manner" (Campos *et al.* 2003). Students show enthusiasm when their learning is more intuitive and interactive, resulting in meaningful learning. Therefore, digital games are raising as a primary tool for learning, motivating the student and developing different levels of personal experience, in order to help the construction of new discoveries, the personality development, among other positive aspects (Oliveira Neto & Ribeiro, 2012).

Accordingly, to help students learning about heart morphology and physiology; specially the rhythmic control and continuous blood pumping through the heart, the cardiac cycle puzzle was developed (Marcondes & Amaral, 2014). It is a simple and inexpensive game that has been used as an active teaching strategy and was considered useful for learning by students from Dentistry, Medicine, Biology, Nursing and Pharmacy undergraduate courses (Marcondes *et al.* 2015). Besides that, when the puzzle replaced part of the lecture, it increased learning (Cardozo *et al.*, 2016), and reduced test anxiety and stress in dental students (Cardozo *et al.*, 2020a). Considering the good acceptance of the printed puzzle by students and professors, its online version has been developed as a digital educational tool. The aims of this work were to describe the development process of the online digital version of the cardiac cycle puzzle, and to evaluate the student's perception of the utility of the digital game for their learning, during emergency remote teaching due to COVID-19 pandemic.

## 2 State-of-Art

### 2.1 Active Teaching Methodologies

In the university, it is difficult for students to maintain attention during traditional lectures because from their childhood, they have access to information and communication technologies, and like to be always connected to a network of contacts, receiving simultaneous stimulus (Abdulmajed *et al.* 2015). Therefore, it is a

challenge for them to be focused when old teaching methods are used (Abdulmajed *et al.* 2015; Luchi *et al.* 2019). In addition, although traditional lecture-based class is effective to present information, it did not promote deep and long-lasting learning or development of problem-solving skills (Campos *et al.* 2020).

As possible solutions to these problems, various active teaching methodologies (Berbel, 2011), aiming to produce creative, critical, and collaborative individuals have been proposed in recent years. These include problem-based learning, projects and teamwork, design/visual thinking, education maker, flipped classroom, hybrid teaching, e-learning, personalized teaching, competency-based education, and game-based learning. Such approaches aim to awaken in the student a state of acceptance of the information received (voluntary action), engage them in relation to the knowledge presented (motivation), create an unconditional attraction of the applied methodology (seduction), and provide an ongoing stimulus to continue the proposed activities (reward).

## 2.2 Digital Games in Education for Health

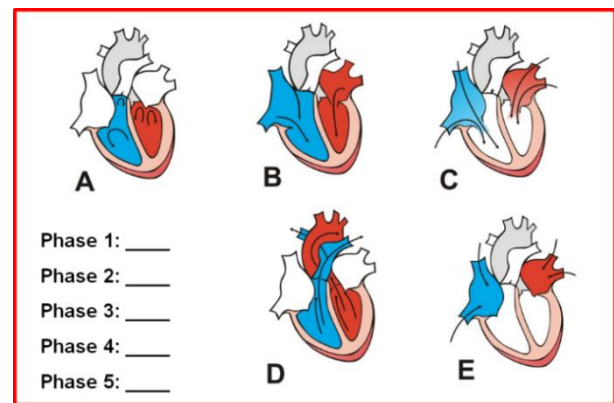
Digital games provide stimulation that takes the forms of challenge, curiosity, control, fantasy, competition, cooperation, and player recognition (Savi & Ulbricht, 2008). They are tools that can enrich pedagogical practice and have received attention among educational researchers and professors who support their use in learning. Digital games have the potential to provide highly engaging environments, offering high levels of interaction and feedback (Machado, 2104), in addition to allowing free experimentation that can enable learning that is pleasurable, captivating, entertaining, and engaged (Bueno, 2010). They also affect the players in ways that include voluntary action, motivation, seduction, and reward, addressing the challenges and opportunities associated with the needs of young people (Satrio *et al.* 2020). Consequently, classes become more attractive (seduction), awakening the students' curiosity and attention (motivation), improving school productivity, assisting professors to make classes more dynamic (reward), and contributing to the students taking advantage of the school outside the classroom (voluntary action).

Serious games can be used as educational strategy to improve the performance of health care professionals by increasing their learning, skills and attitudes (Nøhr & Aarts, 2010; Akl *et al.* 2013). Serious games are complete and playfully games that are developed not for entertainment, but with specific educational objectives (Sisler & Brom, 2008). This is a new and important technology that has been used in specialized training, including 3D games and motors of games to improve the realistic experience of users (Wattanasoontorn *et al.* 2013). Though the advancement of technology and due to the desire to achieve good health in an interesting and fun way, several serious games for health have been developed in recent years (Wattanasoontorn *et al.* 2013),

involving themes related to the transmission of knowledge of first aid and medical information (personal level); to training of competences in health care (professional skills); for recruiting people (research and academy); and to the management of simulations (public health) (Sawyer, 2008).

## 2.4 Cardiac Cycle Puzzle

In the original printed version (Marcondes *et al.* 2015), the cardiac cycle puzzle presents a figure board in a paper A4 size, as in **Figure 1**, a table in a paper A3 size accordingly to **Figure 2** and chips measuring 5.7 x 2.5 cm, laminated with transparent plastic. **Figure 3**. In stage 1, the students in groups are requested to use the figure board to organize five images according to the correct sequence of cardiac cycle phases. **Figure 1**.



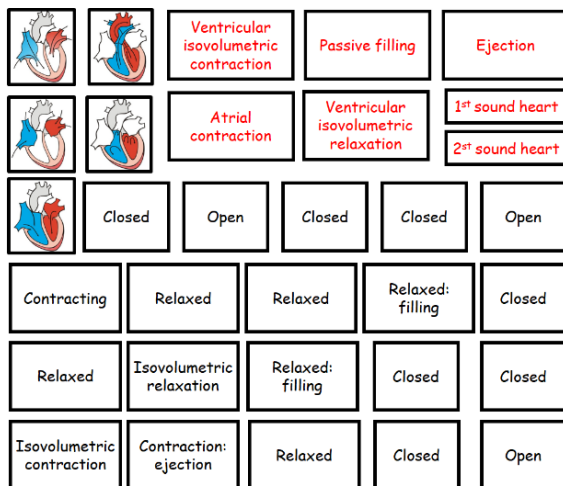
**Figure 1.** Stage 1 of printed cardiac cycle puzzle (adapted from Marcondes et al. 2015).

In the stage 2, they should place the chips in a table. **Figure 2**. The columns of the table indicate: phases of cardiac cycle, atrial and ventricular state, state of atrioventricular and pulmonary valves. **Figure 2**.

Cardiac cycle phase	Phase	Atrial State	Ventricular state	State of atrioventricular valves	Aortic and pulmonary

**Figure 2.** Table for placing chips in stage 2 of printed cardiac cycle puzzle (adapted from Marcondes et al. 2015).

The chips indicate the names of the cardiac cycle phases, atrial or ventricular contraction or relaxation, valves opening and closing. **Figure 3**. (Marcondes & Amaral, 2014; Marcondes *et al.* 2015).



**Figure 3.** Chips for filling the table in stage 2 of printed cardiac cycle puzzle (adapted from Marcondes et al. 2015).

In the stage 3, the groups receive questions to be discussed and answered. These questions address basic concepts related to the cardiac cycle and its application in clinical situations, and can be adapted for different courses (Marcondes et al. 2015; Cardozo et al. 2016).

This educational game has basic characteristics of a puzzle: challenge, feedback, entertainment, and eureka factor (Michalewicz et al. 2011). The challenge is present because the students have to remember, discuss and integrated their knowledge to place each chip in the correct place and to answer the questions (Marcondes et al. 2015; Cardozo et al. 2016). The immediate feedback whether or not the pieces have been correctly placed is provided by monitors or professor, who inform if there was an inaccuracy. If so, they ask questions to enable the students to find the mistake and correct it. The same approach is used considering the correction of questions. This way, the teaching-learning process became dynamic and funny. When all the pieces are correctly placed in the table, there is the hit (Eureka!) and the students feel a sense of reward for solving the puzzle (Michalewicz et al. 2011; Cardozo et al. 2016), as well as when the answers to each question is correct.

This serious game can be used as a complementary strategy (Marcondes et al. 2015), after the lecture, or as an active learning method by replacing a lecture (Cardozo et al. 2016; 2020a). In both cases, the aim of the cardiac puzzle is to help the students to integrate previous knowledges in order to understand how the morphological and physiological characteristics of the heart contribute to the continuous pumping of blood. The aim of this game is to promote collaborative learning. For this, the movement of the pieces and discussion of the questions would be done according to a consensus of the group of students performing the activity (Marcondes et al. 2015; Cardozo et al. 2016; 2020).

### 3 Methods

#### 3.1 Development of the online digital version of the cardiac cycle puzzle

The construction of the digital version of the Cardiac Cycle Puzzle was carried out in two main phases. The first consists of defining a JSON model able to represent a puzzle matrix and possible correct answers according to the arrangement of the fitting pieces. The second, on the other hand, produces a Javascript application from a web game engine capable of interpreting each modeled JSON, thus creating a generic and reusable solution for different desired educational puzzles.

##### 3.1.1 The JSON model

Five main elements were defined in a JSON model to represent drag'n'drop games in a puzzle-style matrix, which were properly configured for the educational game of the cardiac cycle: *tokens*, *columns*, *rows*, *fixed* and *answers*.

*Tokens* indicate the pieces that need to be placed in the matrix cells that represent the puzzle. Each token has a unique identifier (*id* property), the image to be displayed in the game (*image* property), a reference value to be assigned to the puzzle piece (*valueRef* property), and the piece size information (*height* and *width* properties). **Figure 4.**

The matrix itself is composed by the *columns* and *rows* elements, which indicate: an identifier for the respective row and column (*id* property), the label of the respective row or column (*header* property) and the desired column length (*width* property) and line height (*height* property) for the puzzle array. **Figure 4.**

*Fixed* informs which pieces will be placed in the puzzle at startup. For this, it is necessary to inform the piece that will be placed in a fixed way (*id* property with the id value of the token), as well as the line (*rowId* property) and the column (*columnId* property) where it will be fixed in the puzzle. **Figure 4.**

```
export var gameConfig = { id:"ciclo-cardiaco", title:"Ciclo Cardíaco",
  subTitle:"Posicione as fichas em sequência, de acordo com as fases ...",
  timeLimit:120, livesLimit:3,
  timeText:"Tempo:", livesText:"Vidas:", scoreText:"Acertos:",
  attemptsText:"Tentativas:", backgroundImage:"", backgroundSound:"looping.mp3",
  pressButtonSound:"press.wav", winnerSound:"ta-da.mp3", loserSound:"fail.mp3",
  verifyButtonText:"Corrigir Resposta", showAnswerButtonText:"Mostrar Respostas",
  nextSceneButtonText:"Próximo", wrongAnswerText:"Resposta errada! Tente ...",
  ...
  tokens:[
    {id:"token1", image:"cardio1.png", valueRef:"1", height:96, width:96},
    {id:"token2", image:"cardio2.png", valueRef:"2", height:96, width:96},
    ...
  ],
  columns:[{id:"c1", header:"1", width:96},
    {id:"c2", header:"2", width:96}, {id:"c3", header:"3", width:96},
    {id:"c4", header:"4", width:96}, {id:"c5", header:"5", width:96}
  ],
  rows:[{id:"r1", header:"", height:96}],
  fixed:[{id:"token4", columnId:"c1", rowId:"r1"}],
  answers:[
    [ {valueRef:"4", columnId:"c1", rowId:"r1", score:"1"},
      {valueRef:"1", columnId:"c2", rowId:"r1", score:"1"},
      ...
    ],
    [ {valueRef:"2", columnId:"c1", rowId:"r1", score:"1"},
      {valueRef:"4", columnId:"c2", rowId:"r1", score:"1"},
      ...
    ],
    ...
  ],
  ...
}
```

**Figure 4.** Partial example of a JSON model configuration representing one of the modeled cardiac cycle puzzles.

Regarding the valid *answers* to the proposed puzzle, it is possible to inform different combinations of pieces that can be considered as valid answers for the game. In this sense, answers are represented as a matrix of combinations of pieces in certain positions that represent a valid answer to be accepted by the game. For that, each cell of this matrix will be represented by the *Ref* value of a piece to be placed in a respective row (*rowId*) and column (*columnId*) of the puzzle, followed by a possible score value (*score* property) to be associated with this position in the puzzle. **Figure 4.**

### 3.1.2 The Javascript interpreter

To perform the interpretation of the modeled JSON files, a Javascript application based on the Phaser3 web game engine was developed. It performs the initial loading of the images and sounds configured in the JSON model for the configured game, as well as rendering the matrix's representative grid with its respective headers. The inclusion of a Head-Up Display (HUD) according to modeled game dynamics, the rendering of the puzzle pieces deck to be distributed in the matrix, the drag'n'drop control of the pieces according to the matrix cells, and the verification of correct answers and game score according to player attempts, are also executed by the developed application.

The loading of the game media is defined based on the information configured in JSON. For this, some properties referring to sounds such as *backgroundSound*, *pressButtonSound*, *winnerSound* and *loserSound*, together with the properties associated with the images of the tokens, are used to indicate the destination paths of the respective media. A deck for game pieces was also made available for the game, which is filled in at the start of each game with the images and dimensions configured for each token.

The grid rendering is done by including Phaser3 *zone* components, according to the dimensions informed by the columns and rows elements. Each zone controls the drag'n'drop of the game pieces, centralizing pieces partially placed in the respective cells of the configured puzzle matrix. Input and output events for the mouse and parts in the zones are also managed for the purpose of color changes and consequent indication of drag'n'drop status for the respective players.

With respect to the game's HUD, this can display: the time the player still has available to solve the puzzle, the number of lives the player still has in the game, the number of hits the player got with the attempt made, and the number of attempts made by the player. In this way, there are several possibilities for configuring game dynamics capable of gamifying a simple drag'n'drop of puzzle pieces according to game designer interests.

Two buttons are also placed for the player's use in the HUD, which allow: checking if the player's answer is correct, and showing one of the possible correct answers configured in JSON (if the game has already ended). By pressing the "Check" button, the application will check if there is any combination of pieces distributed in the puzzle whose values of the valueRef property are in equivalent positions according to at least one of the position vectors indicated in the JSON matrix answers. It is worth noting that this response

verification will only occur when all the pieces of the deck are distributed in the puzzle matrix. The display of the puzzle response, an action performed when the "Show" button is pressed, will also only occur when all the player's attempts are exhausted.

A message bar is also available in the game, which allows the display of possible game responses based on player's interactions. Among these, the game can: inform that the player's answer is right or wrong, indicate the number of attempts made, warn that all the pieces need to be distributed in the matrix so that an answer can be evaluated, and explain that some actions only can be done before or after the game is over.

### 3.1.3 Online digital cardiac cycle puzzle

The digital version was developed using the figures and answers of the original printed cardiac cycle puzzle, including stages 1 and 2. These stages were made available at <https://ciclo-cardiaco.herokuapp.com/> in three languages: Portuguese, English and Spanish. Stage 3 was not used in the digital version, because in this stage, the questions for group discussion could be adapted for each course and time schedule. Therefore, the questions could be changed and presented to the students according to the preferences of the professor, as described in item 2.4.

The available stages have no time or attempts limits, allowing the player to make mistakes as many times as necessary to learn the correct combinations suggested as responses to the cardiac cycle. **Figure 5.**

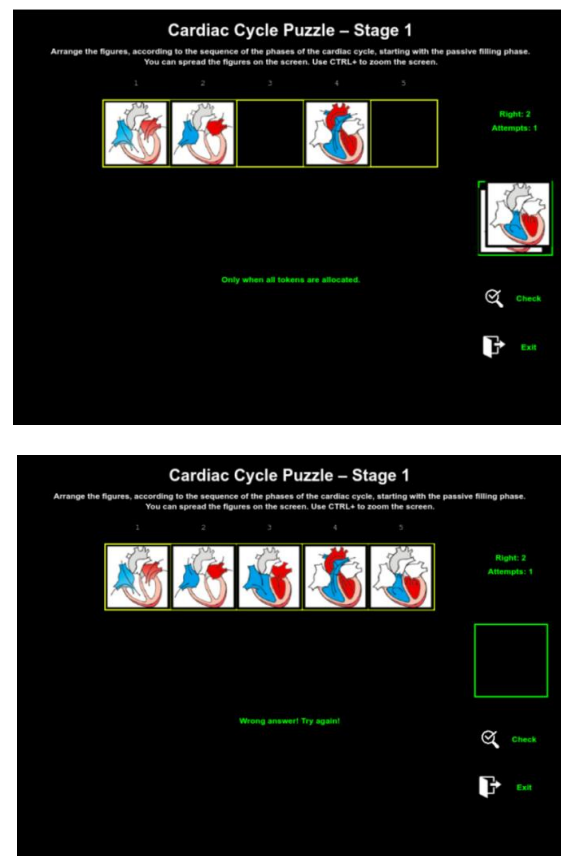
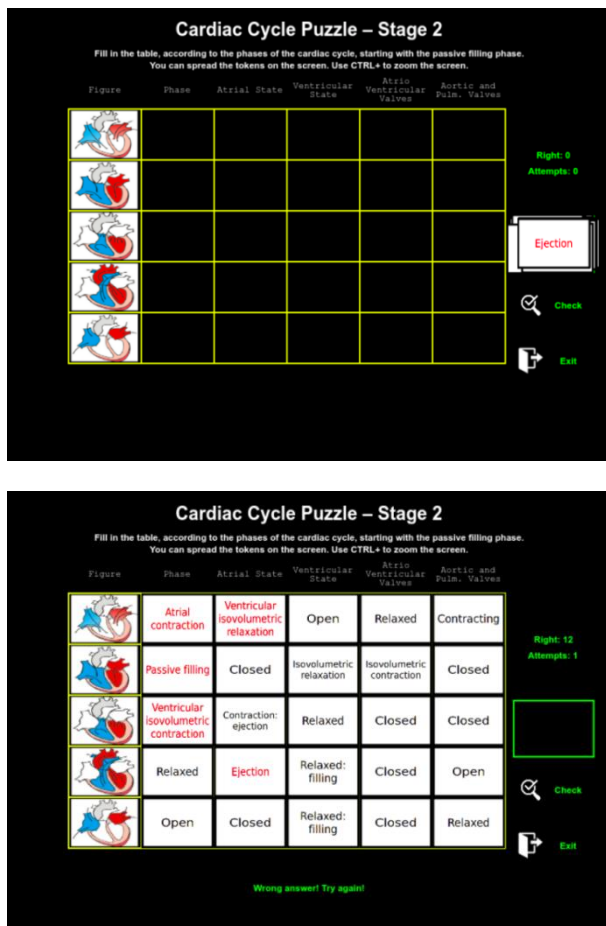


Figure 5. Stage 1 of the online digital cardiac cycle puzzle.

In the first stage, 5 images are illustrated, showing the path of arterial and venous blood in the heart, as well as the contraction and relaxation of the atria and ventricles. It is up to the player to find a possible valid combination between two configurations identified as possible valid responses, by placing the pieces in the cells indicated by the puzzle matrix. **Figure 5.**

In the second stage, a puzzle with five columns and six rows is presented. The columns indicate the phases of the cardiac cycle, atrial status, ventricular status, atrioventricular valve status and pulmonary and aortic valve status. The pieces to be placed indicate the names of the phases of the cardiac cycle phase, atrial and ventricular contraction or relaxation, opening and closing of valves. It is again up to player to find a possible valid combination according to the two configured as possible right responses, by placing the pieces in the cells indicated by the puzzle matrix. **Figure 6.**



**Figure 6.** Stage 2 of the online digital cardiac cycle puzzle.

### 3.2 Students' perception

A prototype of the online digital version of the cardiac cycle puzzle was tested by professors of Physiology at different university institutions. Based on the users' experiences and the feedback received, the online game was validated and improved (Cardozo et al. 2020b). The final version of the game, with improvements made during the validation process (Savi et al. 2010; Cardozo et al. 2020b), was used in remote teaching during the COVID-19 pandemic.

#### 3.2.1 Teaching use of online digital cardiac cycle puzzle

The digital puzzle was used in three courses in the health area, as described below.

Course 1: From 74 students enrolled in the first year of the Dentistry course of Piracicaba Dental School, studying the Biosciences II discipline, 44 agreed to participate in this study. Four students who did not watch pre-class videos before the activity with the educational game were excluded of the study. Therefore, there were 40 participants: 15 men and 25 women. The online digital cardiac cycle puzzle was used as a strategy that replaced the lecture about this subject, as previously described for the printed version, after a short first class addressing the characteristics of cardiac cells (Cardozo et al. 2016). In adapting to emergency remote teaching, part of content of class 1 was presented in 3 pre-class videos of 10, 2 and 9 min, addressing: 1 – introduction to cardiovascular system and pacemaker cells, 2 – cardiac conduction fibers and 3 – contraction of cardiac muscle cells, respectively. These videos were made available for the students, 2 days before the class 1, in the free *Edpuzzle* platform. The videos presented slides and oral explanation of the professor and questions so that the students could check their understanding. *Edpuzzle* generated a report indicating which students had watched each video until the end, and how many questions each student answered.

In class 1, there was a 1h20-synchronous and interactive lecture by *Google Meet*, in which the professor presented the same questions of the pre-class videos. The students answered them by free *Mentimeter app*, anonymously, one at a time. Just after, each question was corrected, and the professor discussed the doubts by using slides in *PowerPoint* software program. In addition, it was also explained how the autonomous nervous system controls the cardiac function. According to the use of printed version (Cardozo et al. 2020), the students were then instructed to use a textbook to study the topic addressed in the classroom, as well as the topic of the next class (the cardiac cycle). The lecturer explained that the content taught in the theoretical class, together with reading of the book, would enable the students to understand the topic addressed in the next class. The lecturer also informed that at the beginning of the next class, there would be a new individual test, followed by an educational game activity (Cardozo et al. 2020). It has been informed that this test, as well as watching the videos before class1, would not be graded by right answer, but by participation. This strategy has been used in order to stimulate the previous study before the activity with the game. At the end of this class, the lecturer sent an exercise to students by e-mail. It should be made in group to be sent to the lecturer until 4 days after class 1. This way, each group would receive its correction with formative feedback, before class 2, that was done 6 days after class 1.

At the start of the class 2 (synchronous by *Google Meet*), there was a discussion of doubts of the students considering the topics addressed in class 1 and studied in the book. The students were divided into 16 groups (5 - 6 students / group). This class was conducted by one professor and 3 monitors

and was repeated 2 times with 8 groups a time. The lecturer then presented a *YouTube-video* showing the movement of blood in the heart during the cardiac cycle. Afterwards, the students answered, individually, a test performed using the *Socrative student app*. After this test, the lecturer presented the instructions for the activity with the cardiac cycle puzzle. The groups of 5-6 members were divided in *Google Meet* break-out rooms and received the link access to the online digital version of the puzzle. It was instructed that only one student from each group accessed the link, shared the computer screen and manipulated the pieces, during discussion in group. The movement of pieces would be done according to a consensus reached by all the group members, in order to promote collaborative learning (Cardozo et al. 2020). In the stages 1 and 2 of digital cardiac cycle puzzle, the groups received feedbacks in the computer screen indicating if the solution was or not right. When the students had doubts, they called the lecturer or monitors by using the cell phone application for exchanging messages *Whatsapp app*. As well as in the activity with the printed version, the role of the lecturer and monitors was not to indicate where errors lay and correct them, but to encourage the students to rethink, discuss among themselves, and solve the problem. If, after discussion, the group was unable to find the errors, and pass stages 1 or 2, the lecturer or monitors asked questions intended to guide the students towards achieving correct positioning of all the pieces (Cardozo et al. 2020). For stage 3, the groups received the questions one at a time, to be discussed and answered in the *Socrative student app*. Each group then called the lecturer or monitors by *Whatsapp app* for answers' correction. All the activity lasted 2h.

Course 2: Twenty-one Pharmacy students from the second year of UFCSPA were enrolled in the Physiology discipline in which the online digital game was used, and seventeen students gave informed consent, consisting of 13 women and 4 men. During the period of the COVID-19 pandemic, emergency distance learning was adopted, and lecture classes were made available in asynchronous (as videos) and synchronous classes (as exercises, games, discussions and doubts). In this course the online digital game was used as a reinforcement strategy. In class 1 (asynchronous), the students watched a video class about the cardiac cycle, make notes and were instructed to study the theme. This video was recorded by the professor, using the *PowerPoint* software, and it dealt with the anatomy of the heart, its muscular characteristics, action potential of the pacemaker cells and cardiac muscle contraction, as well as the physiology of the cardiac cycle and the control of cardiac function (Frank-Starling Law and Autonomic Nervous System). The video lasted 1 h and 45 minutes and it could be paused and resumed at any time, in addition to being able to be watched more than once, as the students deemed necessary. It was made available for the students 7 days before the activity with the online digital version of the cardiac cycle puzzle. The students were also instructed to study the topic in the indicated books and their doubts could be forwarded to a group by *Whatsapp app*, in which the discipline professor and the monitors also participated.

At the beginning of the class 2 (synchronous by *Google Meet*), all students said they had watched the video class. The professor explained how the online digital game works, showing on her screen images of it. The students were divided into 5 groups of 4 members in *Google Meet* break-out rooms. One student from each group was instructed to display the game on their screen and then everyone could discuss and solve the two stages of the game. The professor stayed in the main *Google Meet* room as the beginning of the class to answer students' questions. Three monitors participated in the activity, alternately entering in *Google Meet* rooms to monitor the activity and elucidate questions without, however, answer the game. This part of the activity lasted 1 hour. Once the game was over, all students came back to the main *Google Meet* room to discuss the activity, listen to the explanation about the cardiac cycle by projecting textbook images and elucidate their doubts with the professor. Then, the professor started to present the questions that make up the game using free *Mentimeter app*. Each question was presented in professor screen and the students were instructed to talk through *Whatsapp app* to mark the consensus response of the group members. Then, the professor presented the answers of the groups and, together with the students, discussed the answers, indicating what was correct and incorrect. At the end of the activity, there was an opportunity to clarify any doubts that students might still have.

Course 3: Seventy-seven medical students from the first year were enrolled in the Physiology and Biophysic II class in which the online digital game was used. Seventy-two students gave informed consent. Five students were excluded from the study because they did not answer all the questionnaire questions on student perception. Therefore, 67 students participated in this study, consisting of 54 women and 13 men.

During the COVID-19 pandemic period the hybrid teaching system was adopted by the UNIARA medical course. The lectures were in virtual format with synchronous meetings by *Google Meet*. The practical classes were in person in the laboratories, according all the health protocols recommended by the Brazilian health agencies. For the activity using the online digital version of the puzzle of the cardiac cycle, the students participated in one synchronous virtual lecture (class 1, 50 min) and one face-to-face meeting at lab (class 2, 1 h).

The main concepts related to the cardiac cycle was presented by the professor during the virtual lecture. Mainly, the mechanisms of control of the electrical and mechanical activities of the heart, the ventricular volumes, venous return, cardiac output, ejection fraction, cardiac valves functions, and the autonomic and endocrine controls of these mechanisms. In addition, the cardiac cycle phases have been briefly described. For this, slides from the *Power Point* software were used. The students were encouraged to participate in the discussions, mainly because the professor exemplified the important relationships between cardiac physiology and biophysics with cardiology, highlighting the importance between preclinical and clinical areas. For the lab activity, students were instructed to read the content provided in the textbooks indicated in the medical course syllabus.

Three weeks after the class1, the face-to-face lab activity was carried out with the online digital version of the puzzle. Participants (n = 67) were divided into 22 groups (3 - 4 students / group). The activities were conducted by two professors (11 groups / professor), and it was repeated 3 times by each one, following the health recommendations. Although the students were instructed to read the content in the textbooks before the activity, it was not possible to know in fact if they had studied. Students were informed about the link access to the online digital version of the puzzle, and they were instructed about the activity dynamics. It was suggested that only one student from each group accessed the link and manipulated the app during discussions with other members of the group. Smartphones (16 groups), tablets (4 groups), and laptops (2 groups) were used. Throughout the activity, professors were available to guide student discussions. Whenever a group requested for the professors help, they guided the discussion in order to assist students in the cardiac cycle reasoning. Professors never showed students how the table should be completed. The goal has always been to stimulate students' thinking about the heart functions and discussion among group members. At the end of the activity, as soon as the groups correctly completed the two stages of the virtual game, some questions related to heart functions were presented to the groups using *Power Point* slides. Each question was individually presented, and students were instructed to discuss it; first, within each group and then between groups. This dynamic facilitated the groups interactions, stimulating discussions within the group and between groups. Professors were present encouraging the participation of all members of each group during discussions and raising questions that could be added to discussion complement about heart physiology.

### 3.2.2 Analysis of students' perception

In this study, analysis was made of the students' perception concerning the usefulness of the game activity for their learning. The work received approval from the Research Ethics Committees of the participating institutions: CAAE 10859119.0.0000.5418, Piracicaba Dental School (FOP-UNICAMP); CAAE 42980515.0.3002.5345, Federal University of Health Sciences of Porto Alegre (UFCSA); and CAAE 40019820.9.0000.5383, University of Araraquara (UNIARA).

Analysis of the students' perceptions of the online digital version of the cardiac cycle puzzle was performed in activities undertaken in the Physiology classes of three courses in the health area: Dentistry (n = 40) at FOP-UNICAMP, Pharmacy (n = 17) at UFCSA, and Medicine (n = 67) at UNIARA, totaling 124 students.

The activity employing the online digital version of the cardiac cycle puzzle and questions regarding the students' perception of it were part of mandatory disciplines in the three courses, where all the students participated in all the activities, irrespective of the research. To reduce vulnerability and ensure the students' autonomy in deciding to participate in the research (Tengan *et al.*, 2005), the request to use the data for the purpose of the research was made at the end of the course. The students only participated

in the study after giving free and informed consent (FIC) in digital forms, authorizing the use of their answers concerning the activity with the online digital game.

This study was undertaken while presential teaching activities at the three institutions were suspended due to the COVID-19 pandemic (OPAS, 2020), being replaced by emergency remote teaching delivered in synchronous and asynchronous classes, according to the demands and characteristics of each institution. The resources available and the strategies used by the professors and institutions participating in this study differed in terms of the classes prior to the activity with the online digital cardiac cycle puzzle. This was in accordance with the envisaged use of this educational game, in both printed and digital versions, which depended on the number of hours of teaching, the chronograms of the disciplines, and the learning objectives of the professors in each course. It should be stressed that it was not the objective of this study to make comparisons among the courses, but rather to obtain the students' opinions regarding the activity made with the digital game, without discussing differences related to the characteristics of the courses and the participating institutions.

For analysis of the students' perceptions, after the activity performed with the online digital game, the students from the three courses were requested to answer two questions: 1) "Was the cardiac cycle puzzle activity useful for your learning? Indicate your answer on a scale from 1 to 5, where 1 = *it was not useful for learning* and 5 = *it was necessary for my learning*. Justify your answer". 2) "Did you study for the activity with the cardiac cycle puzzle? Indicate your answer on a scale from 1 to 5, where 1 = *I did not study and did not feel prepared for the activity* and 5 = *I studied sufficiently and felt prepared for the activity*. If you did not indicate 5, explain why you think that you did not study sufficiently or did not feel prepared for the activity".

The Likert-type scale responses were used to calculate the means and standard deviations. Analysis of variance (ANOVA) and Tukey's test were used to identify significant differences ( $p < 0.05$ ). The justifications for the responses were analyzed and grouped. Similar justifications were presented according to the number of students who indicated them. Percentage frequencies were not calculated, because several students provided more than one justification, while others did not justify their answers. Consequently, the total number of justifications did not correspond to the number of students who participated in the work.

## 4 Results

In the opinion of the students of the three courses participating in this study, the activity with the online digital version of the cardiac cycle puzzle was useful for learning (**Table 1**), and the reasons for this evaluation were similar among the courses. For most students, the activity with the online digital game made it easier to understand the addressed topics, allowing to identify what had been understood and the remaining doubts. The students' positive perception was also due to the fact that the educational game presents figures, the activity is dynamic and provides interaction with colleagues.

**Table 1.** Students' perception of the usefulness of the activity with the online digital version of the cardiac cycle puzzle for their learning.

Question	Course 1 (n=40)	Course 2 (n=17)	Course 3 (n=67)
Was the activity with the cardiac cycle puzzle useful for your learning? On a scale of 1 to 5, indicate your answer, considering 1 = it was not useful for learning and 5 = it was necessary for my learning.	4.70 ±0.61 <sup>a</sup>	4.94 ±0.24 <sup>a</sup>	4.79 ±0.48 <sup>a</sup>
<b>Justifications</b>	n <sup>b</sup>	n <sup>b</sup>	n <sup>b</sup>
It made content easier to understand (58)	12	10	36
It showed what I knew and allowed me to identify my doubts (29)	13	2	14
It was more visual, having figures (26)	3	2	21
It made content easier to be remembered (26)	5	1	16
It was more dynamic way to learn (24)	6	2	16
Sharing knowledge with colleagues in the group made me understand better (17)	10	4	3
It sintetized the content (12)	3	0	9
It forces reasoning (11)	2	0	9
It was playful, fun, funny (7)	3	0	4
It was very useful at time of remote teaching (3)	0	0	3
It didn't help much because I missed a class before (1)	1	0	0

<sup>a</sup>mean ± standard deviation of answers in the Likert- type scale (p > 0.05, ANOVA). <sup>b</sup>number of students who presented this justification in each course. Obs.: some students presented more than one justification.

As the use of the cardiac cycle puzzle requires the students to have previous knowledge about the heart, the perception of the students about their previous preparation for the activity was evaluated. The results considering the pre-class study (**Table 2**) show that the study prior to the activity with the online digital educational game differed among the participating students, and the difficulty of organizing time was the main reason for those who evaluated not having studied enough.

**Table 2.** Students' evaluation considering their pre-activity study.

Question	Course 1 (n=40)	Course 2 (n=17)	Course 3 (n=67)
Did you study for the activity with the cardiac cycle puzzle? On a scale of 1 to 5, indicate your answer, considering 1 = I did not study and I did not feel prepared for the activity and 5 = I studied enough and felt prepared for the activity.	4.08 ±0.83 <sup>a</sup>	2.24 ±1.15 <sup>ab*</sup>	3.85 ±0.91 <sup>a</sup>
<b>Justifications</b>	n <sup>b</sup>	n <sup>b</sup>	n <sup>b</sup>
I studied the content and some doubts I had were resolved in the activity (30)	9	3	18
I couldn't organize myself to study all the material (24)	7	7	10
I could have studied more, because I saw that I confused some things (20)	8	2	10
I didn't feel prepared just by reading the content, I miss an explanation in class (5)	3	0	2
I was not feeling well (5)	1	0	4

<sup>a</sup>mean ± standard deviation of answers in the Likert- type scale <sup>\*</sup>significant difference in comparison to course 1 and 3 (p < 0.05, ANOVA + Tukey test). <sup>b</sup>number of students who presented this justification in each course. Obs.: some students presented more than one justification.

## 5 Discussion

The application of a teaching strategy in different courses and institutions enables evaluation of its broader effectiveness. If the strategy is effective, it should work in different contexts, even if not in exactly the same way or to the same degree, with the possibility of adaptations. The results obtained in this study indicated that the students believed that the activity with the online digital version of the cardiac cycle puzzle assisted their learning. These results were similar to those obtained for the printed version of this educational game (Marcondes *et al.* 2015; Cardozo *et al.* 2016).

The opinions of the students regarding the activity evidenced that the teaching strategy was viable in situations of remote teaching or distance learning. In the present case, the fact that the students considered the educational game activity useful was important, but it was not possible to confirm that the teaching strategy increased learning. Often, the student may show a positive reaction because the activity is different to a traditional class, and for this reason, he/she believes that the learning was greater than achieved by only watching a theoretical explanation (Prince, 2004; Cardozo *et*



al., 2016). Although we did not evaluate the students' learning, studies show that the use of active teaching strategies can alter levels of motivation and interest, leading to changes in behavior and making the student feel more inclined to study at home, paying more attention to the topic being studied (Downing *et al.*, 2020).

The cardiac cycle puzzle can be used in different ways, according to the objective of the lecturer, the curriculum structure, and the time available. However, it should be clarified that the purpose of the activity with this educational game, using both the printed and online digital versions, was not to make the teaching process more entertaining. Instead, it aimed to facilitate understanding of a complex subject important for all courses in the health area, which requires of the student considerable study, attention, and ability to integrate the content. The solution of the cardiac cycle puzzle requires basic knowledge of heart morphology and physiology, with the success of the activity in assisting learning being dependent on previous preparation by the student. Therefore, it is crucial that the student should prepare for the activity, follow the instructions given by the lecturer, attend the class prior to the activity, and study the indicated content. In the absence of prior preparation for the activity, the student may like the game, finding it entertaining and dynamic, but without attaining any significant learning. In contrast, much better performance can be achieved when the students have prepared for the activity, when interactions with other group members are positive, and when they are able to have fun, while focusing on the content studied (Montrezor, 2021; Savage *et al.* 2017).

For the three courses evaluated, the justifications for the answers to the question concerning the students' opinion regarding the usefulness of the game were similar. The justification provided by the greatest number of students was that the activity assisted understanding. As observed for the printed version of the same game, applied in a presential class, the results indicated that the students believed that the objective of the educational game had been achieved. The justifications presented by the students contributed to understanding what they most valued in an active teaching methodology. The fact that the answers indicated that the activity with the educational game made it easier to understand the topic suggested that the entire context of the strategy (previous study and the activity with the game, including discussion with colleagues, the monitors, and the lecturer) was useful for learning. Nonetheless, it did not enable elucidation of why understanding the topic became easier.

However, the other justifications allowed the reasons for this positive effect to be identified. The second most frequent justification was that the activity with the educational game enabled the students to identify what they had understood and what their doubts were. This was coherent with one of the precepts of active methodologies, which is to enable the student to accompany the progress made during the teaching-learning process (Kulasegaram and Rangachari, 2018). In the group discussion to define the correct sequence of the figures and the positioning of the cards in the table, indicating the sequence of events of the cardiac cycle, the students were able to explain what they had understood to colleagues, argue

in defense of their understanding of the topic, and reconsider what they believed they had understood. These processes would be unlikely to occur in an exclusively theoretical class, where the student hears, sees, and receives information, without sufficient time to process it during the class (Kulasegaram & Rangachari, 2018; Raes *et al.* 2019).

The use of games allows the student to acquire knowledge in an active and dynamic way, with the individuals involved generally being more open to mutual assistance, with analysis of errors and successes, provoking a deeper reflection on the concepts under discussion (Teixeira and Apresentação, 2014). In the present case, some of the spontaneous justifications are worth highlighting, because they evidence the importance given by the students to the feedback process allowed by the activity with the online digital cardiac cycle puzzle: *"The cardiac cycle puzzle activity enabled me to identify a doubt I had about the cycle, which I didn't even know I had (I hadn't properly understood isovolumetric relaxation and passive filling), leading me to study these specific topics. Hence, this exercise was essential for my learning"*; *"It was very useful, because in the classes employing images and diagrams, I had thought that I understood the cardiac cycle. However, when I performed the game with my colleagues, I perceived that I still had some doubts, which were clarified in the interactions with the other group members and the monitors"*; *"It was necessary, because I could test my knowledge of the cardiac cycle and identify where there were difficulties, in order to be able to subsequently review the subject and resolve my doubts"*. These perceptions of the students were coherent with another premise of active methodologies, namely their association with formative assessments (Hoffmann, 2019). A formative assessment is not necessarily an exam or a test. It may be an informal activity that allows the student to perceive what he/she already knows, so that the study can be reorganized to enable learning of what has not yet been understood. The goal of such an assessment is to evaluate the teaching-learning process, rather than its outcome (Malta *et al.* 2014; Hoffmann, 2019; Cardozo *et al.* 2020; Marcondes *et al.* 2020).

Another reason indicated by the students for the activity with the educational game being useful for learning was that it was "more visual", since it used images. The activity required attentive analysis of the images to identify the route of blood through the heart, the moments of opening and closing of the heart valves, and the contraction and relaxation of the atria and ventricles. Consequently, the students' perception was probably related to the integration of information needed to complete the task. Attentive analysis of the images was also necessary to identify the cards that completed each row and column of the table. Learning is achieved by the use of different sensory organs (Hernández-Torrano *et al.* 2017), with vision being one of the main senses activated during teaching-learning activities (Relvas, 2012). Hence, images assist in the formation of memories and later activation of previously acquired knowledge (Sosa *et al.* 2018). In the present case, the perception of the students showed that they identified the contribution of this process to enhancement of their learning.

The justification indicating that the activity with the online digital game was useful for “it made content easier to be remembered” was the 4<sup>th</sup> most indicated justification, but it was not clear what the students meant. They could have believed that the activity helped in remembering the content worked on, which could have been related to the context and the interactions that occurred during the activity (Hernández-Torrano *et al.* 2017). The fact that it involved visual analysis, together with interaction among colleagues and feedback from colleagues, monitors, and professors, would make it easier to remember what was discussed, explained, and corrected, compared to what would be understood and remembered following a non-interactive taught class.

The dynamic nature of the activity was also indicated as a factor that assisted learning, which was related to the fact that the activity involved different actions and skills, rather than only listening, as would be the case in a traditional theoretical class. This perception was as expected for the use of active teaching methodologies in which the student is no longer a passive listener, instead acquiring an active role that can include speaking, arguing, moving around, and arranging didactic (Hernández-Torrano *et al.* 2017). In this way, the class does not become boring and the students do not lose attention and concentration (Marcondes *et al.* 2021).

The interaction with colleagues was also identified by the students as a factor favoring their learning. Collaborative activities assist in the social construction of knowledge during the interactions between group members, while also increasing the interest and motivation of the students (Montrezor, 2021; Vuopala *et al.*, 2016). Cooperation is effective when the students discover that they share similar objectives, with success depending on the actions of the group. This stimulates and improves interaction among the group, with the members assisting and encouraging others in attaining the learning objectives (Herrmann, 2013). As an example, one of the students provided the following justification of the importance of working as a group: *“I found it very interesting! I had never participated in an activity such as this before, so it was a novelty. I thought it was really useful, because as a group, we discussed and “racked our brains”, in order to understand all the steps and relate them to the heart phases, the atrial and ventricular states, and the opening and closing of the valves, so it was a great experience!”*.

Other justifications provided by the students were less frequent, but nonetheless deserve attention. For some of the students, the activity with the online digital game was useful for learning because it “synthesized the content” and “forced reasoning”. This indicated that the students perceived that in the activity with the online digital game, fundamental concepts were approached in such a way as to enable understanding of them, with this process involving the effort and concentration of the participants. This perception was important for stimulating the students to prepare for the activity and become responsible for their learning, developing self-regulation ability (Polydoro *et al.*, 2015). Consequently, the professor becomes a mediator guiding the teaching-learning process, no longer being a transmitter of information, which is also in accordance with the purpose of active methodologies (Marcondes *et al.* 2021).

Another justification of the students concerned the perception that the activity was “game-based/entertaining”, referring to the fact that it was a more pleasant and relaxed way of learning. As reported by Savage *et al.* (2017), the use of an active teaching strategy provides a more relaxed environment, so that the student feels more at ease in asking questions and making mistakes, resulting in greater interest and motivation. A less formal and more relaxed environment makes the participants feel more comfortable in trying and making mistakes, in addition to reducing the fear of being judged when expressing their doubts, favoring collaborative learning (Lizzio *et al.* 2002; Tyng *et al.* 2017). However, it should be stressed that although a teaching activity may often be entertaining, providing a relaxed atmosphere appreciated by the students, this may not necessarily be reflected in the occurrence of learning (or improved learning). It is essential for the professor to define the intended learning objectives, so that learning actually occurs, avoiding the risk that the active methodology becomes merely a transient distraction (Marcondes *et al.*, 2021).

Three students suggested that the activity with the online digital version of the cardiac cycle puzzle was useful in the context of virtual education, indicating that they valued the online strategy. Although this might seem obvious, it should be noted that this opinion of the students showed that they valued the efforts made to improve the pedagogical practice, confirming that the strategy adopted was effective, in the opinion of the students. This feedback to the professor is very important, since it encourages continuing efforts to improve teaching strategies (Hoffmann, 2012; Marcondes, 2020).

Only one student did not consider the activity with the online digital game useful for learning, because he felt that *“a previous class was lacking”*. The student indicated that he expected the activity to function as a reinforcement of learning. However, in this course, the purpose of the game activity was to replace the theoretical class on the cardiac cycle, not to reinforce what might have been taught in a theoretical class. The opinion of the student could indicate that he was not accustomed to active methodologies that require student participation, reasoning, and interaction. This could have been due to previous experiences in basic education that mainly involved the transmission of information by the professor, resulting in difficulty in adapting to the active teaching strategy (Downing *et al.* 2020). Another possibility is that the student may not have prepared individually before the activity. He may have watched the pre-class videos, but not performed reading of the textbooks, or he may not have understood all or part of what he read. This possibility was related to the second question, as discussed below.

The success of an active teaching methodology depends on the engagement of the student (Downing *et al.* 2020), including periods of individual study. The results of the activity, in terms of student learning, may be poor if the student does not follow the instructions given by the professor. For example, in the present case, the student should watch the pre-class videos (course 1) or the video class (course 2), perform the group exercise before the online digital game activity (course 1), and complete the required textbook readings (courses 1, 2, and 3). It is also essential that clear instructions

are given to the students. In the present study, in addition to providing instructions, the professors explained that previous study would be necessary to enable the students to learn, with mutual assistance, during the group activity performed in the subsequent class. If these prerequisites are not observed, then the results obtained from assessment of the learning achieved, or analysis of the students' perceptions, may indicate that the teaching strategy was unsuccessful. This would not necessarily mean that the approach was ineffective, since its failure would be related to insufficient prior knowledge of the students. In the case of the activity with the online digital game analyzed here, the professors requested the students to undertake previous study using a textbook. In addition to the above considerations, in the present work, analysis of the students' previous preparation was necessary, because the activity with the online digital game was carried out during emergency remote teaching implemented due to the COVID-19 pandemic. Therefore, difficulties related to the pandemic, including access to digital resources, could influence the results of the study, so they should be taken into account. For this reason, the students were also asked if they had undertaken previous study and felt prepared for the activity with the digital version of the cardiac cycle puzzle.

The results showed that the course students participating in the study had not all studied to the same degree, and did not feel equally prepared for the activity. The possible Likert-type scale score varied from 1 to 5, with 5 indicating that the student felt that he/she had studied sufficiently and felt adequately prepared. In two of the courses, the average scores were near 4 (**Table 2**), indicating that the students were of the opinion that they had prepared themselves. However, in one of the courses, the average score was near 2, indicating that the students did not feel prepared for the online digital game activity. Understanding this perception of the students required analysis of their justifications.

In courses 1 and 3, where the students felt prepared for the activity, the most frequent justifications indicated that a score of 5 was not given because they felt that although they had studied, they had remaining doubts, which were resolved in the online digital game activity. This perception of the students was in line with the intended purpose of the active teaching strategy adopted, since it was expected that the activity would be an opportunity for learning. It was expected that the students would have doubts and would not have mastered all the content. Therefore, this justification did not reflect insufficient preparation by the students.

In these courses, as well as in course 2 (where the students believed that they had not prepared sufficiently), the most frequent justification for not feeling prepared was the difficulty of organizing to study, due to inability to efficiently allocate time for their various activities. The second most frequent justification, "*I could have studied more*", did not enable elucidation of whether this was due to difficulty in organizing their time, or, if the student considered that he/she had studied sufficiently, he/she "*confused some things*" during the activity, perceiving that he/she knew less than had been imagined. However, these justifications were not mutually exclusive and showed the difficulty that the students found

in organizing their study, which could be related to the development of self-regulation of learning. Many of the skills expected of students entering university, such as autonomy, critical reasoning, motivation to learn, and knowing how to organize their time for the various activities of the disciplines, are not learned in previous years, during basic education (Polydoro *et al.*, 2015; Cardozo *et al.*, 2020). Furthermore, the inability to organize their time was likely to become more acute during emergency remote education. A small number of students indicated that they did not feel prepared because there was insufficient explanation provided during the class. In other words, they had expected that the online digital game activity would be used as reinforcement, after a theoretical explanation. This justification suggested that the students had not become familiarized with active teaching strategies (Downing *et al.* 2020), which was understandable, given that taught classes still predominate in basic education in Brazil. Therefore, it is essential for the professor to plan teaching activities in such a way as to assist the students in developing the skills described above.

A justification provided by some students from two courses was "*I was not feeling well*". This did not make it clear whether the students were not well during the activity, or during the previous study. Nonetheless, it deserved attention, because it is important that the professor should be sensitive and open to understanding that these situations may arise, preventing the student from benefiting from the active strategy, due to an external factor unrelated to the study or the strategy. During the emergency remote education caused by the COVID-19 pandemic, this understanding was essential to allow the establishment of closer relationships between the professors and the students, including the possibility of repeating the activity or planning other complementary activities for these students. In the context of the pandemic, it is vital that professors understand their role in this new educational process, not only in the use of technologies, but also in ensuring that such resources can be used with all the students, meeting the specific educational needs of each individual (Granjeiro *et al.* 2020).

The use of educational games gives the professor an opportunity to analyze and understand the development of reasoning in the students, making the teaching-learning process more dynamic (Teixeira and Apresentação, 2014). The separate consideration of the results for the three participating courses enabled elucidation of whether the students positively evaluated the online digital game for the same reason or for different reasons. The identification of these reasons supported understanding of how the students' learning occurred, in addition to enabling improvement of the teaching strategy and the development of other similar strategies. For example, if the professor knows that the students greatly appreciate strategies or teaching materials that are visual in nature, it may then be appropriate to use other such tools to reach a greater number of students. If the students place value on group activities and perceive that they learn better with them, it is then necessary to pay special attention to this type of activity, since it can contribute to them developing collaborative learning strategies outside the classroom, improving

their abilities to study, solve problems, and work effectively with colleagues.

In previous work (Marcondes *et al.*, 2015; Cardozo *et al.*, 2016), agreement was observed between the students' perception and the positive effects of the printed cardiac cycle puzzle activity on learning, stress, and anxiety prior to a test (Cardozo *et al.*, 2016, 2020). A limitation of the present study was that it was not possible to perform this assessment, because although the perceptions of the students were evaluated, their learning was not assessed. Since this study was undertaken in the context of adapting didactic activities for emergency remote teaching, it was not possible to use learning assessment tools equivalent to the methods that had been used by the researchers in the present activities and were available at the participating institutions. However, a future study is being elaborated that will allow such analyses.

## 6 Conclusion

This article describes the development of a digital version of the cardiac cycle puzzle, together with the students' perceptions of the effectiveness of its use in higher education. Descriptions are provided of the following aspects: the adaptations made in the digital version, compared to the physical game; details of the implementation of a JSON model representative of the game; the online prototype developed and made available; and the process of analysis of the students' perceptions of the use of the digital version by professors of three undergraduate courses in the health area.

According to the reported perceptions of the students, the digital version of the cardiac cycle puzzle contributed to their learning. Therefore, the digital version seems to be as effective as the original printed version, considering these students' perception.

The online digital game could also be used as an additional resource for individual study and the fixation of learning, subsequent to the group activities, since it may be accessed by the students anywhere and at any time. The digital version of the cardiac cycle puzzle is an active learning resource that could be used by any undergraduate student interested in learning about cardiac physiology.

Finally, it should be highlighted that although the cardiac cycle puzzle was developed to substitute a theoretical class on this topic, it can be adapted according to the learning objectives of the professor, the chronogram of the discipline, and the physical and staffing infrastructure of the institution in which it will be used. Therefore, the development of the digital version of the puzzle expands the possibilities for adoption of this teaching resource.

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## Notes

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## References

- Abdulmajed, H., Park Y.S., Tekian, A. (2015). Assessment of educational games for health professions: a systematic review of trends and outcomes. *Med Teach* 37 Suppl 1: S27-32.
- Abreu, R. N. D. C., Sousa, A.M., Dias, L. M., Almeida, G. H., Diógenes, M. A. R., & Moreira, T. M. M. (2014). Educação em saúde para prevenção das doenças cardiovasculares: experiência com usuários de substâncias psicoativa. *Espaço para Saúde*, 15(3):13–21.
- Akl, E. A., Sackett, K. M., Pretorius, R., Bhoopathi, P. S. S., Mustafa, R., Schünemann, H., & Erdley, W. S. (2013). Educational games for health professionals. *Cochrane Database of Systematic Reviews*, 31(1):CD006411.
- Azer, S. A. (2014). Mechanisms in cardiovascular diseases: how useful are medical textbooks, emedicine, and youtube? *Advances in Physiology Education*, 38(2):124–134.
- Berbel, N. A. N. (2011). As metodologias ativas e a promoção da autonomia de estudantes. *Semina: Ciências Sociais e Humanas*, 32(1):25–40.
- Borges, A. G., Lima, C. O.C., Granjeiro, E. M., Sarinho, V. T., & Bittencourt, R. A. (2016). Body: Um jogo digital educacional de tabuleiro na área de fisiologia humana. *Proceeding of SBGames*, 412–420.
- Bueno, F. (2010). Jogo educacional para ensino de Estatística. *Proceedings do SBGames*, 253-256.
- Campos, L. M. L., Bortoloto, T. M., & Felício, A. K. C. (2003). A produção de jogos didáticos para o ensino de ciências e biologia: uma proposta para favorecer a aprendizagem. *Caderno dos núcleos de Ensino*, 3548.
- Campos, R., Viero, V., Medeiros, N., Marcondes, F.K., Montrezor, L.H., Porawski, M., Gutierrez, L.L.P. (2020). The gut game: an active methodology to teach digestive physiology. *Adv Physiol Educ.*, 44: 444-447.
- Cardozo, L. T., Marcondes, F. K., Montrezor, L. H., Gutierrez, L. L. P., Granjeiro, E. M., & Sarinho, V. T. (2020b). Quebra-cabeça do ciclo cardíaco – Desenvolvimento de uma versão digital online par ao ensino de fisiologia cardíaca. *Proceeding of SBGames*, 997-1004.

- Cardozo, L. T., Azevedo, M. A. R., Carvalho, M. S. M., Costa, R., Lima, P. O., & Marcondes, F. K. (2020a). Effect of an active learning methodology combined with formative assessments on performance, test anxiety, and stress of university students. *Advances in Physiology Education*, 44(4):744–751.
- Cardozo, L. T., Miranda, A. S., Moura, M. J. C. S., & Marcondes, F. K. (2016). Effect of a puzzle on the process of students' learning about cardiac physiology. *Advances in Physiology Education*, 40(3):425–431.
- Downing, V. R., Cooper, K. M., Cala, J. M., Gin, L. E., & Brownell, A.E. (2020). Fear of Negative Evaluation and Student Anxiety in Community College Active-Learning Science Courses. *CBE—Life Sciences Education*, 19(2):1–16.
- Granjeiro, E. M., Musse, J. O., Peixoto, T. M., Nunes, I. V., Soares, I. M. S. C., Silva, I. C. O., Carvalho, T. B., & Dias, Y.O. (2020). Estratégias de ensino à distância para a educação interprofissional em saúde frente à pandemia COVID-19. *Revisa*, 9(1):591-602.
- Hernández-Torrano, D., Ali, S., & Chan, C. K. (2017). First year medical students' learning style preferences and their correlation with performance in different subjects within the medical course. *BMC Medical Education*, 17:131.
- Herrmann, K. J. (2013). The impact of cooperative learning on student engagement: Results from an intervention. *Active Learning in Higher Education*, 14(3): 175–187.
- Hoffmann, J. (2012). *O Jogo ao Contrário em avaliação*. Mediação 9 ed. 176p.
- Hoffmann, J. (2019). *Avaliação mediadora*. Mediação 35 ed. 192p.
- Kulasegaram, K., & Rangachari, P. K. (2018). Beyond “formative”: assessments to enrich student learning. *Advances in Physiology Education*, 42(1): 5–14.
- Lizzio, A., Wilson, K., & Simons, R. (2002). University students' perceptions of the learning environment and academic outcomes: implications for theory and practice. *Studies in Higher Education*, 27(1):27–52.
- Luchi, K.C.G., Cardozo, L.T., Marcondes, F.K. (2019). Increased learning by using board game on muscular system physiology compared with guided study. *Adv Physiol Educ* 43: 149–154.
- Machado, R. S. (2014). Fator diversão na produção de um jogo eletrônico educativo. *Proceedings do SBGames*, 550-559.
- Malta, D. C., Moura, L., Prado, R. R., Escalante, J. C., Schmidt, M. I., & Duncan M. I. (2014). Chronic non-communicable disease mortality in Brazil and its regions, 2000-201. *Epidemiologia e Serviços de Saúde*, 23(4):599–608.
- Marcondes, F. K., Cardozo, L. T., & Azevedo, M. A. R. (2021). Metodologias ativas no ensino superior: o que o professor deve saber para que não seja um modismo? In P.V. Santos. *Metodologias ativas – Modismo ou Inovação?* 1ed. Quirinópolis – GO. Editora IGM. pages 175-189.
- Marcondes, F.K. (2020). Por que diversificar as estratégias de ensino aprimorou minha prática docente. In M.A.R. Azevedo, E.P.C.B.N. Melo, J.P. Pezzato, & I.B.N. Melo. *Ação pedagógica na universidade contemporânea: reflexão e ousadia*. Jundiá – SP. Paco Editorial. 263-277.
- Marcondes, F. K., Cardozo, L. T., Azevedo, M. A. R. (2020). Estratégias ativas de ensino e avaliações formativas no ensino superior. In Costa G. *Metodologias ativas – métodos e práticas para o século XXI*. 1ed. Quirinópolis – GO. Editora IGM. pages 325-338.
- Marcondes, F. K., Moura, M. J., Sanches, A., Costa, R., Lima, P. O., Groppo, F. C., Amaral, M. E., Zeni, P., Gavião, K. C., & Montezor, L. H. (2015). A puzzle used to teach the cardiac cycle. *Advances in Physiology Education*, 39(1):27–31.
- Marcondes F., & Amaral, M. (2014). Entendendo a fisiologia do coração por meio de um quebra-cabeças. In C. E. Signorini, O. Raymundo Jr., & R. Roselaine, editor, *Práticas Pedagógicas no Ensino Superior*. Ed. Fundação Hermínio Ometto–UNIARARAS.
- Michalewicz, Z., Falkner, N., & Sooriamurthi, R. (2011). Puzzle-based learning: An introduction to critical thinking and problem solving. *Decision Line*, 42(5):6–9.
- Montezor, L. H. (2021). Lectures and collaborative working improve the performance of medical students. *Advances in Physiology Education*, 45(1):18–23.
- Nøhr, C., & Aarts, J. (2010). Use of “serious health games” in health care: a review. *Information Technology in Health Care: Socio-technical Approaches 2010: from Safe Systems to Patient Safety*, 157:160.
- Oliveira Neto, A. A., & Ribeiro, S. A. B. (2012). Um modelo de role-playing game (rpg) para o ensino dos processos da digestão. *Itinerarius Reflections*, 8(2).
- Organização Pan-Americana da Saúde (OPAS). (2020). Folha informativa – COVID-19 (doença causada pelo novo coronavírus) - Principais Informações. *Representação da OPAS no Brasil, 2020*. [https://www.paho.org/bra/index.php?option=com\\_content&view=article&id=6101:covid19&Itemid=875](https://www.paho.org/bra/index.php?option=com_content&view=article&id=6101:covid19&Itemid=875).
- Polydoro, S. A. J., Pelissoni, A. M. S., Carmo, M. C., Emilio, E. R. V., Dantas, M. A., & Rosário, P. (2015). Promoção da autorregulação da aprendizagem na universidade: percepção do impacto de uma disciplina eletiva. *Revista Educação PUC-Campinas*, 20(3): 201–213.
- Prince, M. (2004). Does Active Learning Work? A Review of the Research. *Journal of Engineering Education*, 93(3): 223–231.
- Raes, A., Vanneste, P., Pieters, M., Windey, I., Van Den Noortgate, W., & Depaepe, F. (2019). Learning and instruction in the hybrid virtual classroom: An investigation of students' engagement and the effect of quizzes. *Computers & Education*, 143:103682.
- Relvas, M. P. (2012). *Neurociência na prática pedagógica*. Rio de Janeiro, RJ. Editora Wak. 1 ed. 168 pages.
- Satrio, K. B., Solehuddin, M., & Saripah, I. (2020). What generation z needs in education: A survey. *Proceedings of the 2020 The 6th International Conference on Frontiers of Educational Technologies*, 30–33.
- Savage, B. M., Lujan, H. L., Thipparthi, R. R., & DiCarlo, S. E. (2017). Humor, laughter, learning, and health! A brief

- review. *Advances in Physiology Education*, 41(3):341–347.
- Savi, R., Von Wangenheim, C. G., Ulbricht, V., & Vanzin, T. (2010). Proposta de um modelo de avaliação de jogos educacionais. *RENOTE-Revista Novas Tecnologias na Educação*, 8(3).
- Savi, R., & Ulbricht, V. (2008). Jogos digitais educacionais: benefícios e desafios. *Renote*, 6(1).
- Sawyer, B. (2008). From cells to cell processors: the integration of health and video games. *IEEE computer graphics and applications*, 28(6):83–85.
- Sisler, V., & Brom, C. (2008). Designing an educational game: Case study of europe 2045'. In Z. Pan, A. D. Cheok, W. Müller, & A. El Rhalibi, editor, *Transactions on entertainment I. Lecture Notes in Computer Science*, volume 5080 Springer, pages 1–16.
- Sosa, P. M., Gonçalves, R., Carpes, F. P., & Mello-Carpes, P. B. (2018). Active memory reactivation previous to the introduction of a new related content improves students' learning. *Advanced in Physiology Education*, 42:75–78.
- Tarouco, L. M. R., Roland, L. C., Fabre, M-C. J. M., & Konrath, M. L. P. (2004). Jogos educacionais. *RENOTE: revista novas tecnologias na educação [recurso eletrônico]*. Porto Alegre, RS.
- Teixeira, R. R., & Apresentação, K. R. S. (2014). Jogos em sala de aula e seus benefícios para a aprendizagem da matemática. *Revista Linhas, Florianópolis*, 15(28): 302-323.
- Tengan, C., Venancio, P. C., Marcondes, F. K., & Rosalen, P.L. (2005). Autonomy and vulnerability of subject in scientific research. *Revista de Direito Sanitário*, 6(1):25–37.
- Tyng, C. M., Amin, H. U., Saad, M. N. M., & Malik, A.S. (2017). The influences of emotion on learning and memory. *Frontiers in Psychology*, 8:1454.
- Vuopala, E., Hyvönen, P., & Järvelä, S. (2016). Interaction forms in successful collaborative learning in virtual learning environments. *Active Learning Higher Education*, 17:25–38.
- Wattanasoontorn, V., Boada, I., García, R., & Sbert, M. (2013). Serious games for health. *Entertainment Computing*, 4(4):231–247.