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Use of Several Grids in the Knight Tour's Game to Find Shorter or Longer Biochemistry's Sentences

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Abstract

Knight tour is a mathematical problem that was first solved by Leonhard Euler (1707-1785). The problem consists in finding if it is possible that the knight piece of chess can tour through all the boxes of a chess grid, passing only once through each box. Bishop piece can only move to diagonal boxes of one color, and pawns can only move in one column. It can be easily seen that king, queen and rook can move through all the boxes. But it was not clear that the knight could move all through. Euler found several solutions for the 8x8 grid, and he numbered all the boxes of the grid in the order through which the knight passed. Surprisingly, he obtained some solutions with semi-magic squares, in which the sum of all the numbers of each row and column was the same. Nevertheless, diagonals didn't sum the same, as happens in the magic squares. One of the typical games in word game's books is the knight tour, with a 5x5 grid, that hides a 25-syllable sentence. The objective of this work was to study other grids, to obtain different sentences length with 3x3 (9-syllables), 4x4 (16-syllables), 5x5 (25 syllables), 6x6 (36 syllables) or 7x7 (49 syllables) grids. Thus, this game would be more versatile and could be used more extensively than limiting it to 25-syllable sentences.

Introduction

Games are highly appreciated by most people, and it can be used as a good learning method, because students are stimulated by games when they try to solve them, feeling as they are not carrying out an active study. This learning method, currently called gamification, was already used by Maria Montessori [Palmarola, 2017]. Montessori's method should be used as an educational method for students up to 18 years old, and although our Biochemistry's students of the Chemistry degree are about 20 years old, the method could be also applied to them because there is no much differences between 18 and 20. Games give several benefits to those who play them, as they allow a temporary escape from daily problems and can improve psychological and stress problems of the players. These benefits come from the satisfaction of solving a problem, that initially seems to be difficult for them, feeling much better when they obtain the solution. In order that students could learn using games, they must be caught by the game and enjoy playing it [Prensky, 2000]. In this sense, gamification methodology allows the student to acquire more knowledge and skills, without using passive traditional teaching methods [Kim, 2013]. Escape-rooms with several pages containing different kind of games are a good methodology to catch students. Although some games could not be interesting for students, others in the Escape-room will be. Escape-room thread will be an incentive

for the student to continue the game, although in a certain page a non-interesting game is found.

By age and sex, games are usually more appreciated by men than by women, and younger people play much more than older ones. For this reason, Biochemistry students of the Chemistry degree are adequate to use this kind of methodology for their self-learning. In the last years, and taking advantage of the pandemic situation, in our teaching innovation group (QuiMet, Metabolisme en Química, GINDOC-UB/180), we proposed several games to be used by students to self-learning biomolecules [Moreno y Centelles, 2021; Centelles et al., 2022a]. Games published in entertaining books can be classified into two large groups, those based on numbers (sudokus, number tables, addition, or subtraction games) and those based on letters (anagrams, crosswords, mazes, hangman). Although some numerical problems are often used in Biochemistry teaching, games based on letters can be better adapted to learn biomolecules names and structures. The first games that we prepared and adapted for Biochemistry were the dot-to-dot based drawings, although dot numbers were replaced by intermediate metabolites of a metabolic pathway, and students should organize ordering these metabolites. Later, we adapted games based on mazes with labels (instead of dots), mazes with questions and answers, or mazes in which letters are found along the way. Word searches, crosswords, anagrams, codes, chained words [Centelles et al., 2022b] and even traditional knight tour's games (with a 5 x 5 grid) were also used. However, although there are numerous solutions to the knight tour's game for a 5 x 5 grid, sentences should always contain 25 syllables, and sometimes it is difficult to prepare a sentence with this number of syllables. Therefore, in this study we consider the possibility to use other grids to prepare games containing other syllables sentences.

The problem of the knight tour was for first studied by Leonhard Euler (1707-1785), using the chessboard (8 x 8 grid). The problem was to identify if there were complete routes, in which the knight could jump through all the boxes on the grid without repeating any box. It was clear that the bishops cannot go through all the boxes, since they only go through the boxes of their own color (white bishop or black bishop). In the same way, the pawns advance only along their column, and they will not be either able to go through all the boxes. This does not happen with rooks, king, and queen, which can go through all the boxes by following neatly one after the other rows and columns. But, however, it was not clear if the knight could tour through all 64 boxes on the grid. Euler found several solutions, numbering the boxes through which the knight was jumping, from 1 to 64 [Watkins, 2004]. One of the solutions that he obtained is shown in Figure 1, in which a semi-magic square is observed. In semi-magic grids, all rows and columns add up to the same number, but unlike magic squares, the diagonals do not add up to the same [Weisstein, 2021]. Likewise, for this grid he also found a cyclical closed solution, that is, one complete route, in which it was possible to jump from box 64 to box 1 again with the movement of the knight.

Compared to the 5 x 5 grid, the 8 x 8 grid allows much more complete knight's tours, and therefore it could be more difficult to find the hidden sentence of the game. This last grid contains 64 syllables sentences, as opposed to the 25 syllables in the 5 x 5 grid. Thus, the main aims of this work were the following:

– Use the knight's tour game for the continuous evaluation of Biochemistry students of the Chemistry degree at the University of Barcelona.

– Analyze different grids to be able to use this game preparing shorter or longer Biochemistry sentences.

Grids commonly used in this game are 5 x 5 grid, that allowed 25 syllables sentences. This 5 x 5 grid allows 304 complete knight's tours [Hingston and Kendall, 2005]. Therefore, we tried to look for other possibilities, using

square or rectangular grids, where the sentences could be shorter, (3 x 3, 3 x 4, 4 x 3, 4 x 4, 4 x 5, and 5 x 4 grids) or longer (5 x 6, 6 x 5, 6 x 6 and 7 x 7 grids).

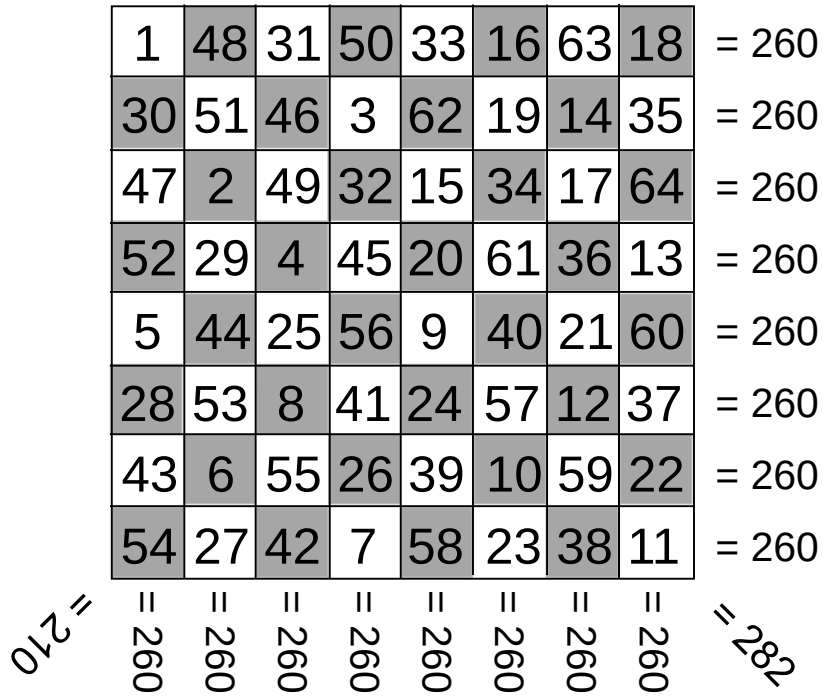


Figure 1. One of the Complete Solutions of the 8 x 8 Grid Knight Tour Solved by Euler, that is also a Semi-magic Square

Method

Closed Roads in the Knight Tour's

The chess knight movement involves a horizontal or vertical jump in any direction and a diagonal jump in any other direction. Thus, from any central box (x,y) it is possible to move to the following 8 boxes: (x+2, y+1), (x+2, y-1), (x-2, y+1) , (x-2, y-1), (x+1, y+2), (x-1, y+2), (x+1, y-2) and (x+1, y-2) (see Figure 2a). These movements are extremely reduced when starting from edge boxes or from corner boxes of the grid. Starting from a corner box, only 2 jumps are possible (Figure 2b), which imply adjacent knight jumps. These positions can be closed to a new intermediate position, forming a closed path in the shape of a diamond. On the other hand, when knight jump positions are not adjacent, it is also possible to form a closed path, which in this case is a square path (Figure 2c). Unlike diamond paths, which can start from one corner of the grid, square paths cannot be generated from the corner of the grid, but from an edge box on the side of the grid.

As Figure 2 shows, depending on the origin box, knight jumps may be higher or lower, between 2 and 8. Thus, starting from the dark box of (a) 8 jumps are possible, while from the dark box position of (b) only 2 jumps are possible, and from the dark box of (c) 3 jumps are possible (only 2 jumps are shown). Figure 3 shows the possible knight jumps from each box in the 5 x 5 grid.

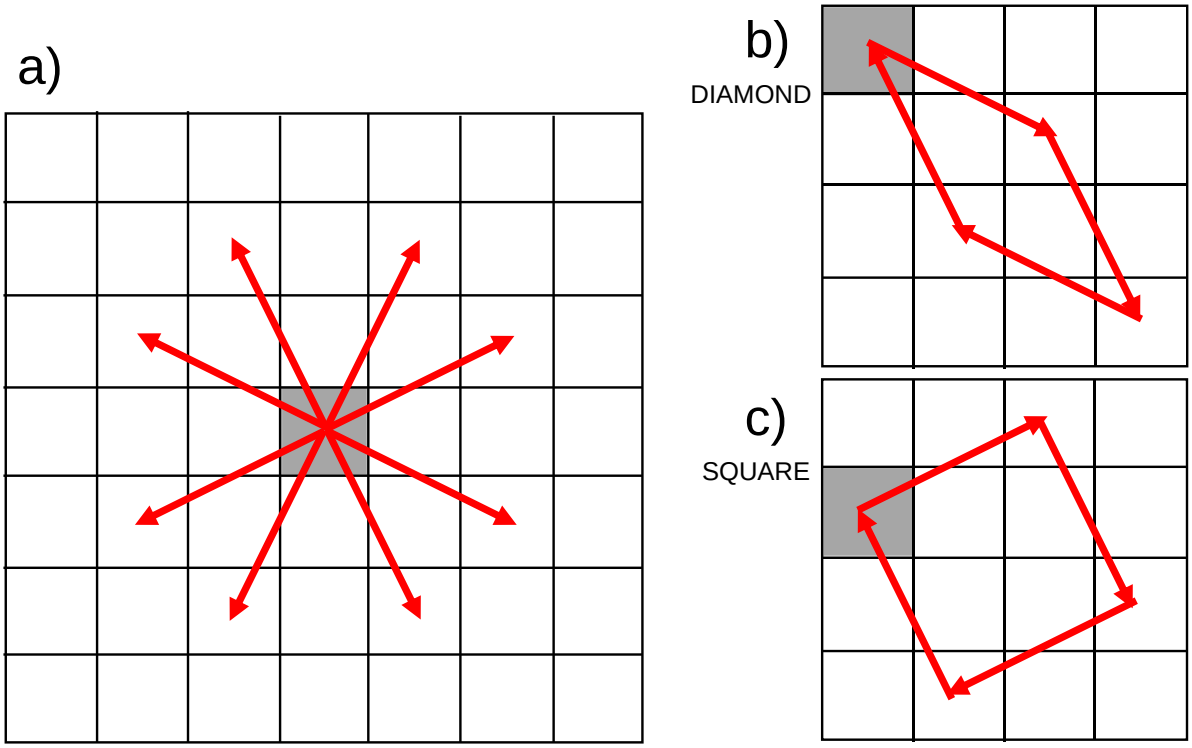


Figure 2. Study of the Possible Knight Jumps, and the Easier Closed Routes. a) Positions where the knight can move from a central box (marked in grey). The horse can jump to 8 different positions. b) Diamond, which is obtained from the closed tour of two adjacent jump positions. The origin box from a diamond tour may correspond to a corner box of the grid. c) Square, which is obtained from the closed tour of two non-adjacent positions. The origin box from a square tour does not correspond to a corner box, but to an edge box on the side of the grid.

(2)	(3)	(4)	(3)	(2)
(3)	(4)	(6)	(4)	(3)
(4)	(6)	(8)	(6)	(4)
(3)	(4)	(6)	(4)	(3)
(2)	(3)	(4)	(3)	(2)

Figure 3. Study of the Number of Knight Tour Possible in a 5 x 5 Grid. Each box shows the number of jumps that can be performed from each box position.

Symmetry of the Grids

Square-shaped grids have several symmetry axes. Figure 4 shows the equivalence of boxes in a 5 x 5 grid. Independent boxes have been marked with black letters. The two diagonal symmetry axes and the horizontal and vertical axes show the symmetry of the grid. Thus, even though the 5 x 5 grid has 25 boxes, only 6 of these boxes must be analyzed to know the possible knight's tours observed in the complete grid. Analyzing the routes starting from any of these 6 boxes, it is possible to know the routes from any of the other 19 remaining boxes of the grid. Boxes marked with grey letters are symmetric boxes from the other 6 boxes, thus showing the same number of tours as their symmetric box.

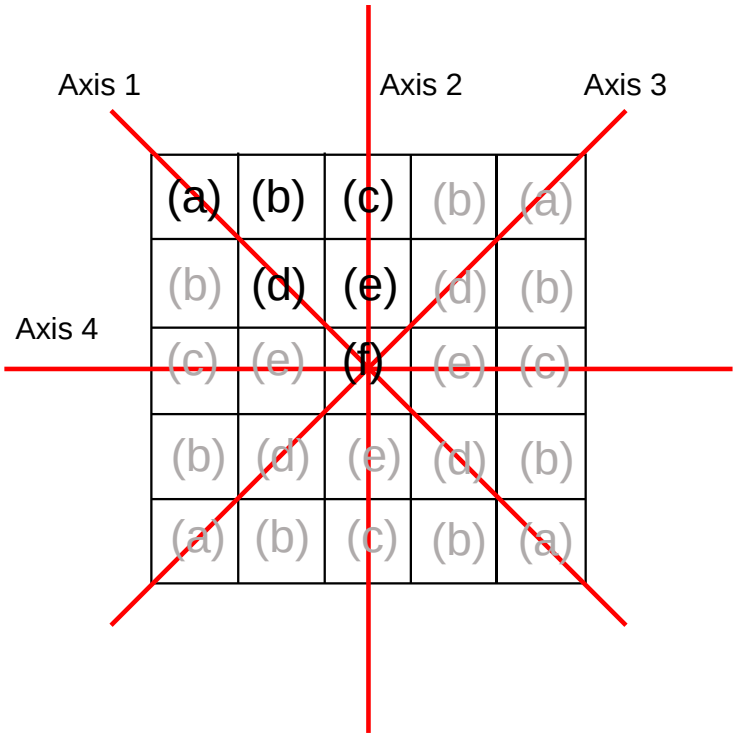


Figure 4. Study of the Symmetry Axis of a 5 x 5 grid. The two-diagonal axis (axis 1 and 3) and the horizontal (axis 4) and vertical (axis 2) axis limit a group of 6 boxes, from which it is possible to identify the tours from other boxes by symmetry. The total number of tours of this grid will be given by 4 x tours of (a) + 8 x tours of (b) + 4 x tours of (c) + 4 x tours of (d) + 4 x tours of (e) + 1 x tours of (f).

In this paper, the study will be centered on the knight's tours beginning from the upper left corner box (marked as (a) in Figure 4). Usually, for the knight's tour game, this is the initial box in most of the games, since it is easy to identify it with an arrow and write in the statement that the game begins from the box indicated by the arrow. Another symmetry observed in square-shaped grids is the rotation symmetry. The grid can rotate 90º, 180º or 270º.

Results

In this paper, the knight's tour paths starting from the upper left corner box were studied. The upper left corner

box can be marked by an arrow and even use a knight figure to make the game presentation more attractive. Since in our culture, writing is from left to right and from top to bottom, student eyes go directly to the upper left part of the grid, and even more if there is the figure of the horse and the arrow indicating the starting box of the game. We studied different grid sizes to analyze the possibility of sentences using different number of syllables.

3 x 3 Grid

3 x 3 grid contains 9 boxes, but it is observed that knight cannot pass through the central box, since there is no chance to jump from this box to any other on the grid. The possible solutions of the knight tour were analyzed, and it was found that there are 2 knight's tours, although none complete (Figure 5). Those 2 knight's tours use 8 boxes and are cyclic routes, i.e. it is possible to retorn by a single knight jump from box 8 to box 1. In one of the routes, the knight travels in the grid turning clockwise, while in the other one it rotates counterclockwise.

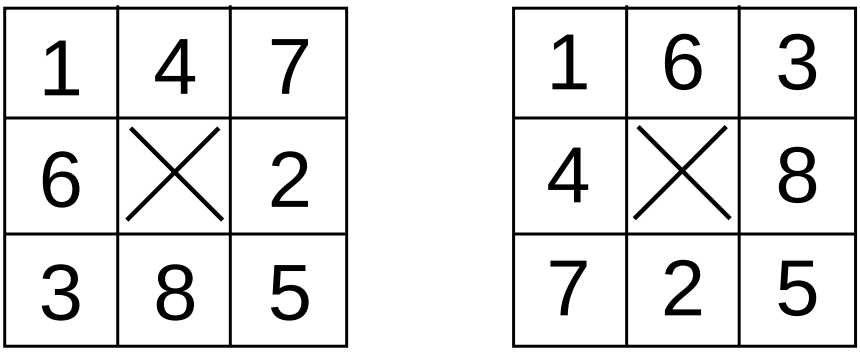


Figure 5. The Two Possible 8-Boxes Route Solutions for a Knight Tour of a 3 x 3 Grid. In the left grid, the knight tour rotates clockwise, while in the right grid, the knight tour rotates counterclockwise. Both solutions are cyclic routes, as it is possible to reach box 1 from box 8 by an extra knight jump. Nevertheless, the central box cannot be reached, and therefore there are not complete 9-boxes tours.

None of the two routes shown is complete since it is not possible to jump to the central box (crossed out in Figure 5). On the other hand, it should be noted that neither of these two incomplete routes is a semi-magic square.

Although a full run (9 boxes) cannot be achieved, the 3 x 3 grid can be used as a game to study Biochemistry, preparing 8-syllable sentences or 8-letter words. In the case of 8-syllable sentences, it is possible to place the syllables YES or NO in the central box and ask a question that can be answered with one of these syllables. The box that has not been used in the knight's tour will give the answer to the question asked as part of the game.
An example of a sentence with 8 syllables and a question is shown in Figure 6. The statement of the game is the following:

Starting from the box indicated by the knight figure, and moving through the knight's tour route, find the name of three nucleobases. The box, where the knight has not passed through, indicates if these nitrogenous bases are pyrimidine bases.

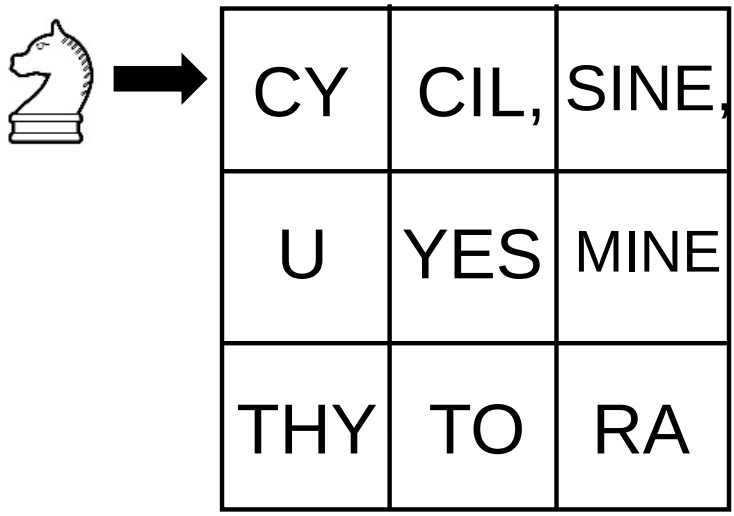


Figure 6. Example of a Knight's Tour Game, Applied to Biochemistry, Using a 3 x 3 Grid. Solution of this game shows that the name of the three nucleobases requested are: "cytosine, uracil, thymine", and the central box indicates yes. Those nucleobases are pyrimidine bases.

Result from the game shown in Figure 6 is: "Cytosine, uracil, thymine". The answer of the central box is YES, these nucleobases are pyrimidine bases. Other nucleobases are purine bases adenine and guanine.

Another example, that uses letters instead of syllables, is the example shown in Figure 7, with an 8 letter-word. The statement of the game is the following:

Starting from the box indicated by the knight figure, and moving through the knight's tour route, find the name of a nitrogenous compound. Is this compound a nucleobase or a nucleoside?

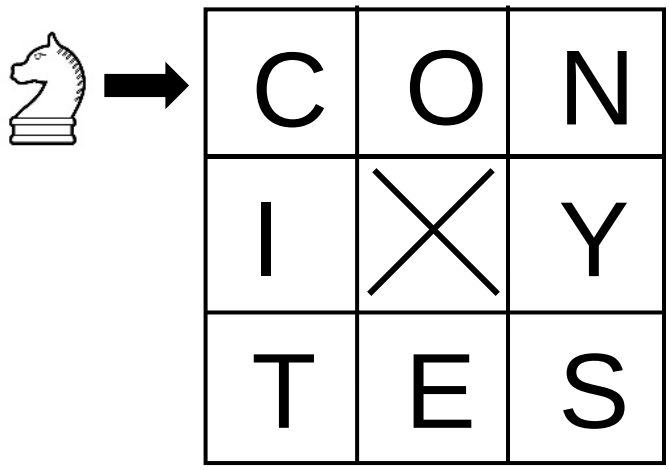


Figure 6. Example of a Knight's Tour Game, Applied to Biochemistry, Using a 3 x 3 Grid. Solution of this game shows the name of a nucleobase: "cytosine". Here, the central box does not show a letter, but the game could ask for the abbreviation of the nucleobase in DNA (C) or its complementary nucleobase (G, for guanine).

Result from the game shown in Figure 7 is: "Cytosine". Cytosine is a nitrogenous base from pyrimidine bases.

This game was prepared to show to the student the differences between purine bases (adenine, guanine), whose nucleosides end in –osine (adenosine, guanosine). On the other hand, cytosine is a pyrimidine base, and its nucleoside is called cytidine. In the central box, it could be asked and placed the abbreviation of cytosine (C) or of the complementary base that could form hydrogen bridges with cytosine (G, for guanine).

3 x 4 Grid

3 x 4 grid contains 12 boxes. Figure 8 shows the nomenclature used for all the boxes, where numbers indicate the different rows and letters the columns. Furthermore, the plot shows the number of jumps allowed from each box, and in red all destination boxes after the jump. On the other hand, the knight's tours with 12 steps, beginning from the upper left box (1a box) are also shown. Figure 9 also contains the knight's tours written as a diagram, as we obtained from the computer program that calculated them.

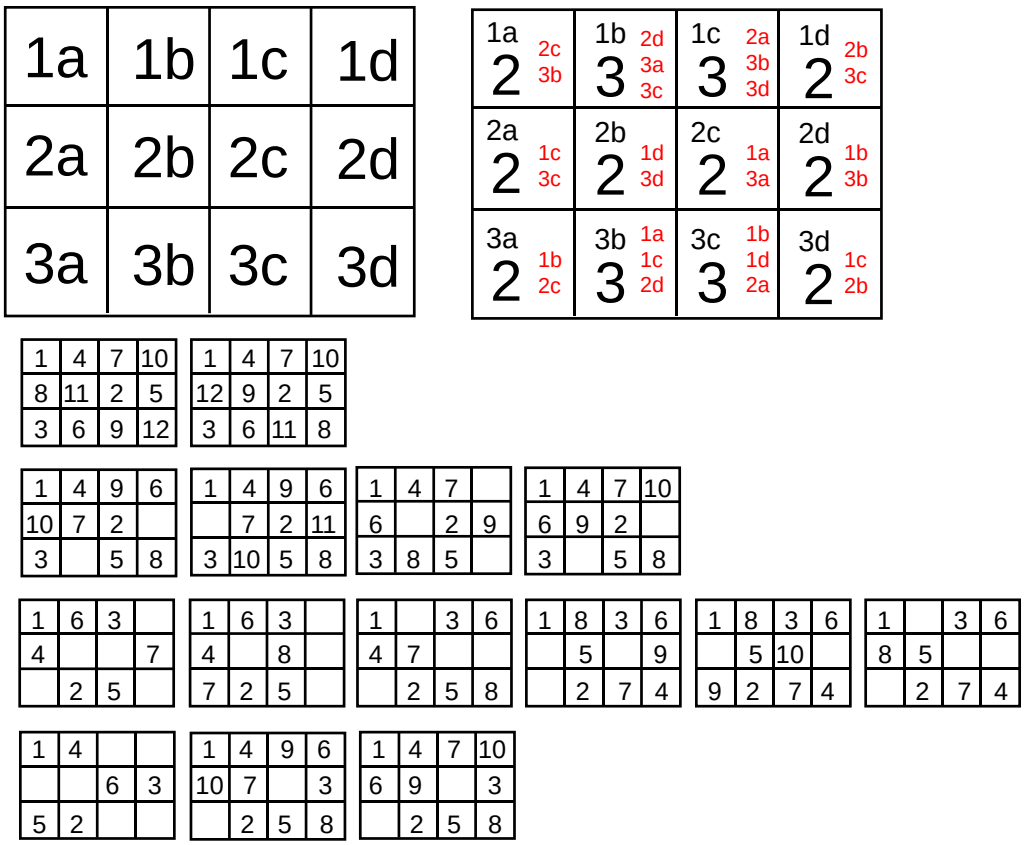


Figure 8. Study of the Number of Knight's Tours in a 3 x 4 Grid. For each box, the destination boxes are shown in red. Knight's tours include 2 complete routes (non-cyclical, with 12 steps), and 13 incomplete routes (1 with 6 steps, 1 with 7 steps, 3 with 8 steps, 2 with 9 steps, 5 with 10 steps, and 1 with 11 steps).

As the 3 x 4 grid is not a square grid, there is no symmetry through diagonal axes. Nevertheless, there are still vertical and horizontal symmetry axes. Most of the boxes allow only 2 jumps (arrive and departure), whereas 4 boxes allow 3 jumps (1b, 1c, 3b and 3c boxes). Starting from the upper left box (1a box), 15 knight's tours (13 of them incomplete) are possible. Those tours are shown in Figures 8 and 9, but only 2 of these routes are complete containing 12 steps, and none of these is a cyclic route. Also, none of these is a magic or semi-magic square.

Obviously, by symmetry it should be observed that similar knight's tours can be obtained beginning from boxes 1d, 3a and 3d. On the other hand, by rotation it should be noted that 3 x 4 grid is like 4 x 3 grid, with the same routes, since one grid is obtained from the other by 90º rotation.

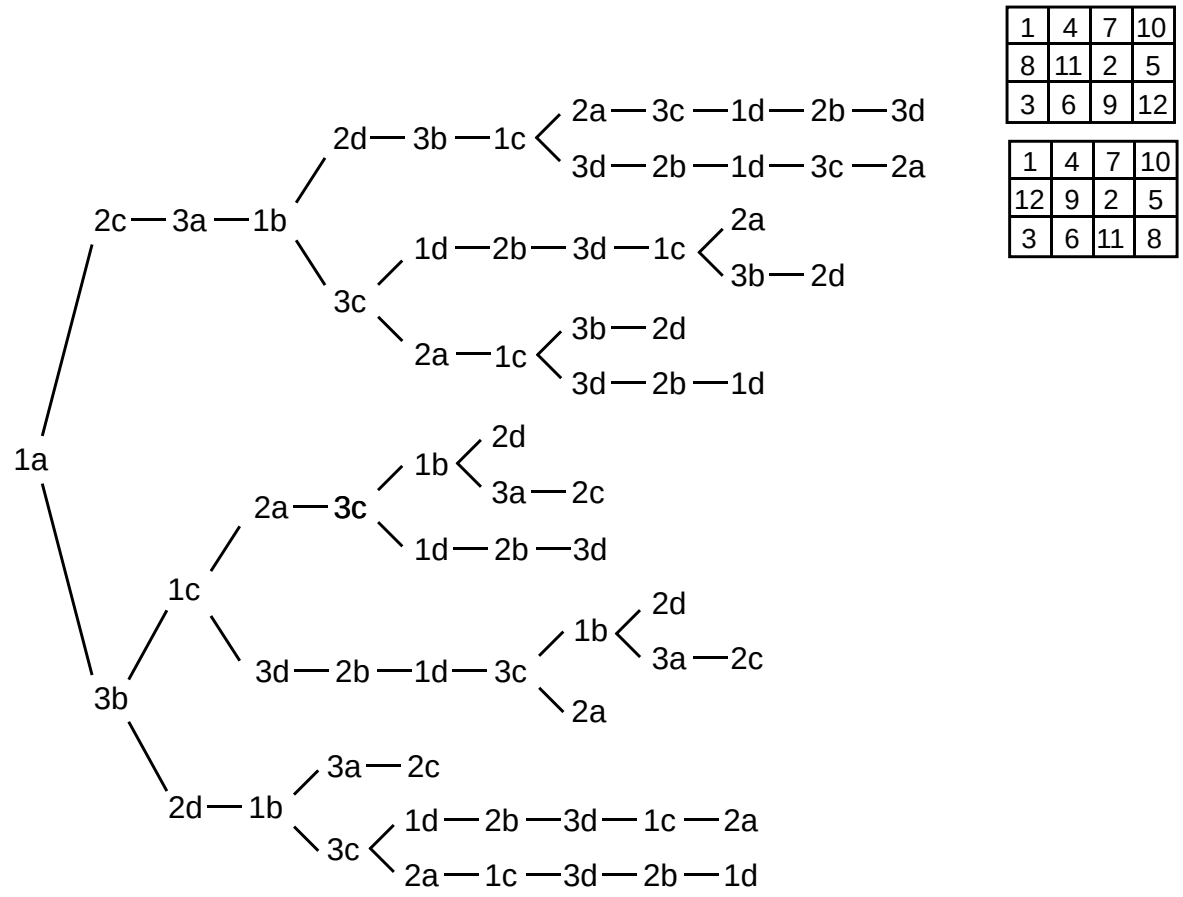


Figure 9. Algorithm that Shows the Possible Knight's Tours for the 3 x 4 Grid, as carried out by the Computer Program that we Developed. As indicated in Figure 8, there are 2 complete (non-cyclic) routes, and the 13 incomplete routes indicated above.

The knight's tours were studied using a program with an algorithm of the different jumps. From a box (x,y) it is possible to jump to the 8 following boxes: (x-1, y+2), (x+1, y-2), (x-2, y-1), (x+2, y-1), (x-2, y+1), (x+2, y+1), (x-1, y+2) and (x+1, y+2), as long as those values are inside the grid. Figure 9 shows all the knight's tours on the 3 x 4 grid, and as it is shown in Figure 8, only 2 complete knight's tours (with 12 steps) are observed.

The complete routes studied hereby are those starting from the upper left box (1a box). 3 x 4 grid contains the same route than 3 x 3 grid, although in 3 x 3 grid sentences contain 8 syllables and in 3 x 4 grid contain 12 syllables. Figure 10 contains an example in Biochemistry of a 12-syllables sentence. The statement of the game is the following:

Starting from the box indicated by the knight figure, and moving through the knight's tour route, find a sentence related to nitrogenous compounds:

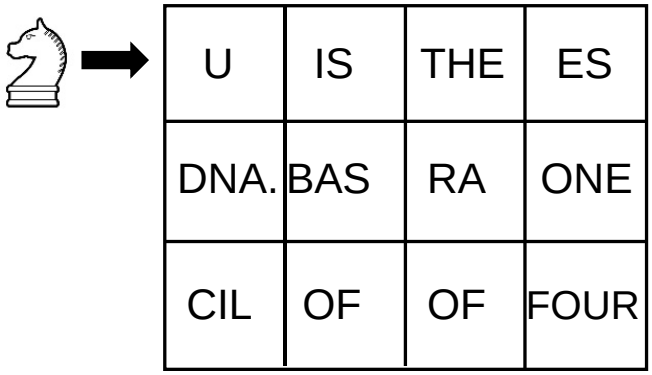


Figure 6. Example of a Knight's Tour Game, Applied to Biochemistry, Using a 3 x 4 Grid. Solution of this game shows the name of a nucleobase: "Uracil is one of the four bases of DNA.".

Result from the game shown in Figure 10 is: "Uracil is one of the four bases of DNA.".

4 x 4 Grid

4 x 4 grid contains 16 boxes. As a square grid, diagonal symmetry allows the study of half routes and obtain by symmetry the other half. For a 4 x 4 grid, it is not possible to obtain complete knight's tours (with 16 steps): Nevertheless, it is possible to find knight's tours with 15 steps. Figure 11 shows these 15 step routes. None of the 15 steps-solution is a magic or semi-magic square. Furthermore, none of them is a cyclic route.

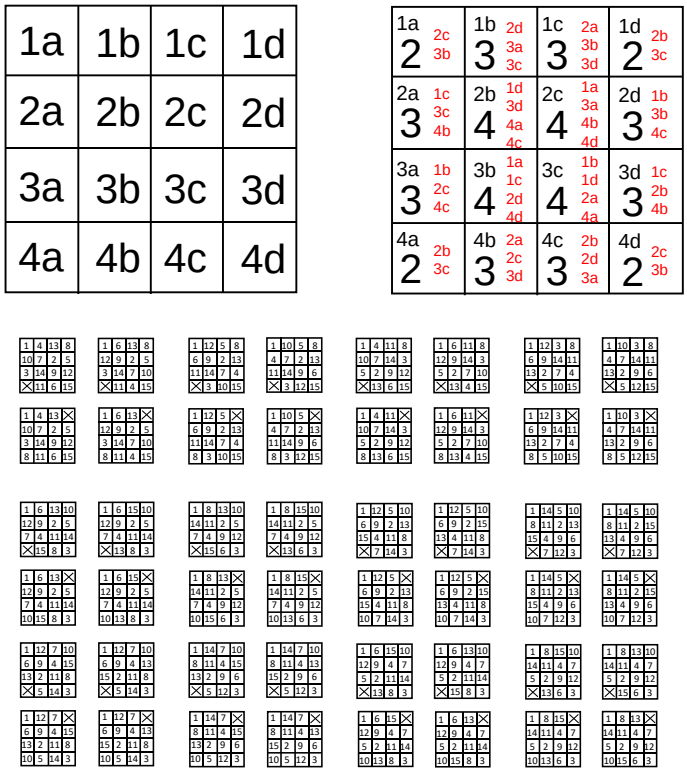


Figure 11. Study of the Number of Knight's Tours with 15 Steps in a 4 x 4 Grid. For each box the destination boxes are shown in red. Routes include 48 knight's tours with 15 steps, but no complete route with 16 steps is possible.

Figure 12 shows two examples in Biochemistry of 15-syllables sentences using a 4 x 4 grid. The statements of these games are the following:

Statement from the game on the left: Starting from the box indicated by the knight figure, and moving through the knight's tour route, find a sentence related to some nitrogenous bases. Solution of this game is: "Cytosine and thymine are pyrimidine present in DNA". Statement from the game on the right: Starting from the box indicated by the knight figure, and moving through the knight's tour route, find a sentence related to adenosine triphosphate (ATP). Solution of this game is: "ATP is either hydrolyzed to ADP and Pi or AMP and PPi".

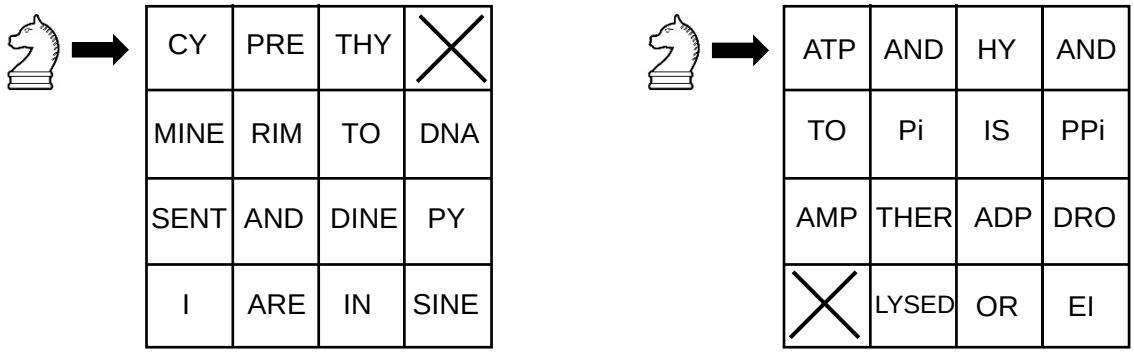


Figure 12. Two Examples of Knight's Tour Games, Applied to Biochemistry, Using a 4 x 4 Grid. Solutions of 15-syllables sentences of these games are: from the grid on the left: "Cytosine and thymine are pyrimidine present in DNA" and from the grid on the right: "ATP: is either hydrolyzed to ADP and Pi or AMP and PPi".

4 x 5 Grid

As for the 3 x 4 rectangular grid, 4 x 5 grid does not have diagonal symmetries. Furthermore, 4 x 5 grid is like the 5 x 4 grid, as it can be seen by rotation symmetry. Complete knight's tours are 32, but these routes are not represented in Figure 13. In this Figure, the nomenclature used is shown for all the boxes, where numbers indicate the different rows and letters the columns. Furthermore, the plot shows the number of jumps allowed from each box, and in red all destination boxes after the jump.

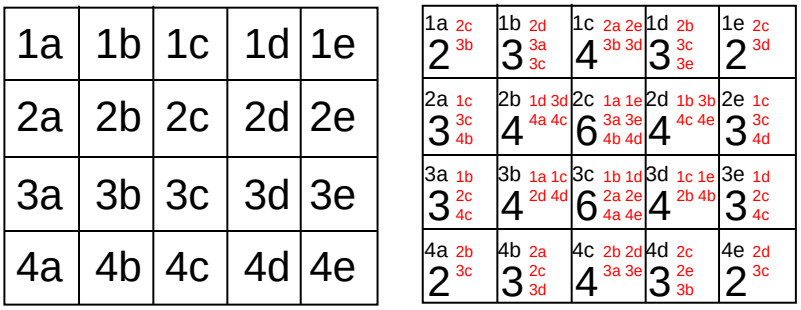
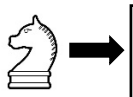


Figure 13. Study of the Number of Knight's Tour in a 4 x 5 Grid. For each box, destination boxes are shown in red. After studying the routes, 12,856 paths are observed, and among them there are 32 complete routes.

4 x 5 grid contains 20 boxes, thus allowing to construct 20-syllables sentences. Figure 14 shows an example in Biochemistry of a 20-syllables sentence using a 4 x 5 grid. The statement of this game is the following:

Starting from the box indicated by the knight figure, and moving through the knight's tour route, find a sentence related to nitrogenous bases. Solution of this game is: "Cytosine is a nitrogenous base, while cytidine is a nucleoside". This game was prepared to show to the student the differences between purine bases (adenine, guanine), whose nucleosides end in –osine (adenosine, guanosine). On the other hand, cytosine is a pyrimidine base, and its nucleoside is called cytidine.



CY	CLE	TROG	DINE	SINE
NI	I	TO	O	BASE,
NU	E	WHILE	IS	IS
CYT	A	A	NOUS	SIDE

Figure 14. Example of a Knight's Tour Game, Applied to Biochemistry, Using a 4 x 5 Grid. Solution of this game shows the sentence: "Cytosine is a nitrogenous base, while cytidine is a nucleoside".

6 x 6 Grid

6 x 6 grid contains 36 boxes, thus allowing to construct 36-syllables sentences. Figure 15 shows an example in Biochemistry of a 36-syllables sentence using a 6 x 6 grid. The statement of this game is the following:

Starting from the box indicated by the knight figure, and moving through the knight's tour route, find a sentence related to nucleobases in deoxyribonucleic acid. Solution of this game is: "In deoxyribonucleic acid (DNA), guanine and cytosine bases form three hydrogen bounds, while adenine and thymine form only two.". This sentence allows the student to analyze the bounds between bases in DNA.

In	hy	a	on	ox	gen
cid	form	de	dro	to	thy
three	cleic	ly	mine	bounds,	y
two.	(DNA),	while	sine	and	cy
nu	form	nine	e	ri	bas
gua	ad	bo	es	and	nine

Figure 15. Example of a Knight's Tour Game, Applied to Biochemistry, Using a 6 x 6 Grid. Solution of this game is the following: "In deoxyribonucleic acid (DNA), guanine and cytosine bases form three hydrogen bounds, while adenine and thymine form only two.".

7 x 7 Grid

7 x 7 grid contains 49 boxes, thus allowing to construct 49-syllables sentences. Figure 16 shows an example in Biochemistry of a 49-syllables sentence using a 7 x 7 grid. The statement of this game is the following:

Starting from the box indicated by the knight figure, and moving through the knight's tour route, find a sentence related to the bounds of nucleotides in DNA. Solution of this game is: "Deoxyribonucleic acid double helix follows Chargaff rules: the amount of adenine is equal to that of thymine and the amount of guanine is equal to that of cytosine.".

De	of	of	e	y	to	is
mount	cy	ox	that	e	qual	ri
thy	ad	that	to	is	nine	qual
of	a	mine,	e	to	bo	of
lows	ru	sine.	nine	mount	a	ble
the	the	Char	lix	dou	gua	nu
gaff	fol	les:	a	cleic	he	cid

Figure 6. Example of A Knight's Tour Game, Applied to Biochemistry, Using a 7 x 7 Grid. Solution of this game is the following: "Deoxyribonucleic acid double helix follows Chargaff rules: the amount of adenine is equal to that of thymine and the amount of guanine is equal to that of cytosine.".

Discussion

Knight's tour games use typically a 5 x 5 grid, which allows to find 25-syllable sentences. However, as studied in this work, other grids can be also used, and solutions with different numbers of syllables can be obtained. This allows to prepare games with sentences about biomolecules, containing more or less than 25-syllables.

Square grids smaller than 5 x 5 do not allow complete tours, as there is always one box that cannot be filled after the knight's tours. Thus, the 3 x 3 grid allows games containing 8 boxes (8-syllables sentences or 8-letters words), and the 4 x 4 only 15 boxes (15-syllables sentences). However, grids larger than a 5 x 5 grid do allow complete tours. Nevertheless, these grids are difficult to solve, as there are many solutions for each grid. 6 x 6 grid allow 36-syllables sentences and 7 x 7, 49-syllables sentences, both being too long sentences and difficult to find. Non-square grids (3 x 4 and 4 x 5, as well as their symmetrical 4 x 3 and 5 x 4) also allow complete tours. Likewise, other grids with different shapes that were not square or rectangular could also be analyzed.

The wide variety of grids means that knight's tour game allows Biochemistry sentences containing 8, 12, 15 or 20 syllable (for smaller grids) and thus it should not be limited to 5 x 5 grid (25-syllables sentences). Larger grids, 5 x 6 (30-syllables), 6 x 6 (36 syllables), 6 x 7 (42 syllables) or 7 x 7 (49 syllables) grids can be also used. Nevertheless, these sentences are usually too long, and too difficult to solve considering that the grid have too many solutions.

Conclusion

Knight's tour game using a 3 x 3 grid allows games of 8 syllables or 8 letters, since they do not allow complete routes of 9 boxes, but only those with 8 boxes. However, the grid allows only 2 tours containing 8 boxes (rotation jumping clockwise and anticlockwise), being an easy game to solve.

Knight's tour game using a 3 x 4 grid (or a 4 x 3 grid) allow games of 12 syllables. However, they only allow 2 complete routes with 12 boxes, being an easy game to solve.

Knight's tour game using a 4 x 4 grid allows games of 15 syllables, since there are not possible complete routes with 16 boxes, but only those with 15 boxes. 48 routes of 15 syllables can be found.

Knight's tour game using a 4 x 5 grid (or a 5 x 4 grid) allow games of 20 syllables. The complete routes are 32, with 20 boxes.

Games using 4 x 4 and 4 x 5 (5 x 4) grids are suitable grids to be used in games. Larger grids could be too complex to solve and sentences too long.

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References

Centelles, J.J., de Atauri, P.R., Moreno, E. (2022a). A new way to study biochemistry words by using games. In S. Jackowicz & I. Sahin (Eds.), *Proceedings of IHSES 2022-- International Conference on Humanities, Social and Education Sciences*, Los Angeles, USA. ISTES Organization

Centelles, J.J., Moreno, E., de Atauri, P.R. (2022b). *Aplicación a la Bioquímica de juegos de palabras encadenadas. Valencia*. https://www.youtube.com/watch?v=_8ftED_dRcU

Hingston, P. and Kendall, G. (2005). Enumerating knight's tour using an ant colony algorithm. *Proceedings of IEEE Congress on Evolutionary Computation.* pp. 1003-1010.

Kim, B. (2013). *Keeping Up With … Gamification. American Library Association.*

http://www.ala.org/org/acrl/publications/keeping_up_with/gamification

Moreno, E. and Centelles J.J. (2021). *Juegos sencillos destinados a aprender la nomenclatura de las biomoléculas*. https://nodos.org/ponencia/juegos-sencillos-destinados-a-aprender-la-nomenclatura-de-las-biomoleculas-en-la-asignatura-de-bioquimica/

Palmarola, J. (2017). *Guía práctica del Método Montessori: Con más de 100 actividades para hacer en casa de 0 a 6 años (Libros de actividades Montessori en casa y en clase)*. ISBN-10: 1973357615; ISBN-13: 978-1973357612.

Prensky, M. (2000). *Digital game-based learning*. New York: McGraw-Hill.

Watkins, J.J. (2004). *Across the Board: The Mathematics of Chessboard Problems*. Princeton University Press. Princeton.

Weisstein, E.W. (2021). *"Semimagic Square". From MathWorld--A Wolfram Web Resource*. https://mathworld.wolfram.com/SemimagicSquare.html

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