# Chem and Roll: A Roll and Write Game To Illustrate Chemical Engineering and the Contact Process

Nicolas Dietrich

# CHEM&ROLL: A ROLL&WRITE GAME TO ILLUSTRATE CHEMICAL ENGINEERING AND THE CONTACT PROCESS

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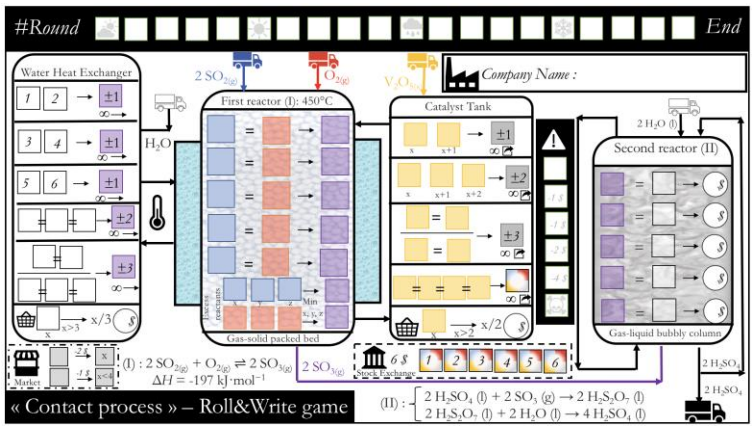
## ABSTRACT

Active learning has recently become considered as a promising strategy to increase the learning outcomes of classes, in particular in the context of chemistry. In this paper an original *roll&write* game is proposed to increase stimulation in the chemistry classroom. The students have to run a chemical plant for sulfuric acid, made with the contact process, and by manipulating dice rolls, they have to optimize and maximize the production of the substance. The students have to choose a dice, representing a reactant in the process, and must combine that dice with others using multiple reactions to produce sulfuric acid. The student can also choose to use a catalyst or to maintain a certain temperature in the reactors to improve the efficiency of the process. The game can be played solo or with a large number of players. A 2-4 player version is also proposed to increase interactivity between players and an advanced version is proposed, which is based on the stoichiometric ratio of each reaction. Playing the game is not the end of the activity: debriefing will highlight the key elements of the construction of this process and will indicate the resources for further research. This activity is a good way to initiate beginners in chemistry as no background is required for playing the game and it is also a good tool for practicing and manipulating chemical concepts for non-beginners. The main advantage is the low cost and simplicity of roll&write games, as only simple material is needed (4 dice) and the scoresheet is available as an easily printable paper sheet.

## GRAPHICAL ABSTRACT




## KEYWORDS

General Public, Chemical Engineering, Collaborative / Cooperative Learning, Communication / Writing, Humor / Puzzles / Games, Reactions /History, Philosophy

## INTRODUCTION

In recent decades, educational games have been successfully employed by many chemistry instructors as instructional devices to complement the usual teaching techniques [1,2]. Educators have developed educational games to involve students in interactive and entertaining activities. Games are an excellent way of active learning and many have been tested [3]. These games can be categorized either by the platform of presentation: word game [4], card games [5–7], board games [8–10], computer games [11,12], party games [13], concentration games [14] and, recently, an escape game [15]. A full review can be found in [1,9].

In all these activities, gaming is seen as an alternative way of encouraging communication among students, and might allow them to learn in a more entertaining way compared with the traditional lecture format [16,17]. However, most of these games need a lot of material and it could be time consuming to print and prepare all the elements necessary to play the game. Here, a game based on the classical “roll&write” game is proposed as an easy and inexpensive alternative educational activity in chemistry classrooms for high-school/college audiences.

## THE ROLL&WRITE GAME

Roll&Write games are usually small, portable games that involve players rolling dice and marking the results on sheets of paper or erasable boards and they sometimes include a solitaire variant. The archetype of these games is Yahtzee, created in 1956, but since then, different kinds of games have appeared, with different themes and twists. Unlike Yahtzee, most modern incarnations of the formula include player interaction, sometimes in the form of dice selection, and sometimes in being the first to complete a certain goal, locking other players out. These games have proven to have a wonderful range of complexity, depth, and theme and have encountered great success in game publishing since 2015.

## THE MATERIAL

The main advantage of this type of game is the small amount of material needed: only a few dice, pencils, and paper sheets (a third of a sheet of A4 paper per player, as depicted in Fig 1-left). The financial investment for the game is less than 1$. The second main advantage is the number of players; as each player will choose a dice individually, the game can be played by 1 to an infinity of players. This advantage makes it possible to play this game with a large number of students for a small investment in material. The game needs four dice of four colors: blue, red, white and yellow. If the dice available are colorless or have the wrong color, an optional module is provided to give a color to a dice (Fig. 1.b). This module and the individual score sheet are provided in the supplementary materials section (pages 1&5).

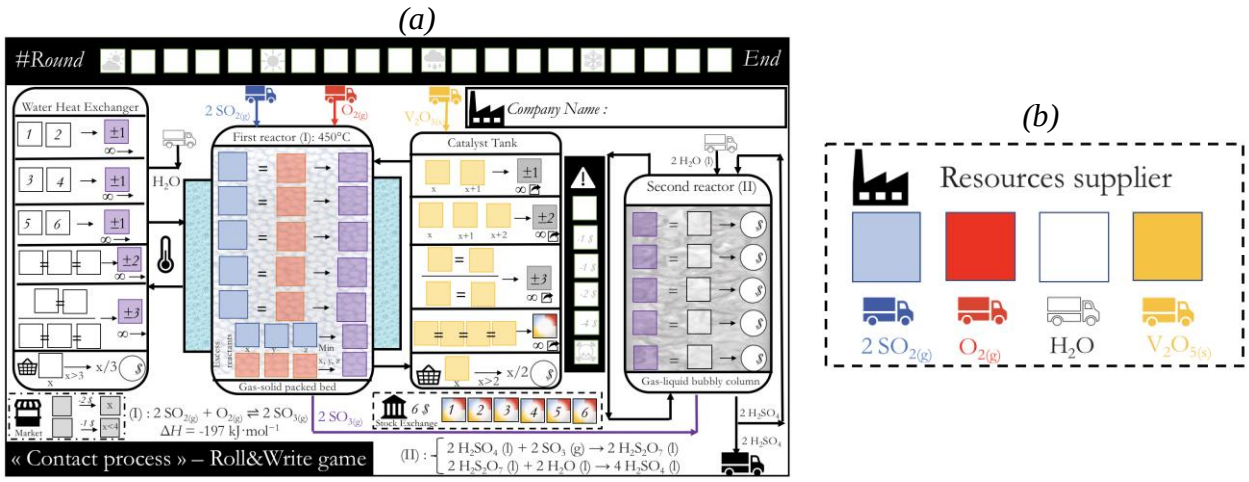



Figure 1. (a) Individual score sheet. (b) An optional module to give the dice a color.

The individual sheet represents a simplified version of the “contact process” flowsheet, where the inlets and the outlets are represented by trucks. The other elements are described in the following section.

## CONTACT PROCESS

The contact process is the current method for producing sulfuric acid in the high concentrations needed for industrial processes. Platinum used to be the catalyst for this reaction but, as it may react with arsenic impurities in the sulfur feedstock, vanadium(V) oxide ($V_2O_5$) is now preferred [18–20]. This process was patented in 1831 by the British vinegar merchant Peregrine Phillips. In addition to being a far more economical process for producing concentrated sulfuric acid than the previous lead

chamber process [21], the contact process also produces sulfur trioxide and oleum. The process can be divided into different stages: the first one is the combination of sulfur and oxygen ($O_2$) to form sulfur dioxide, which can be purified to avoid catalyst poisoning; then a reaction occurs between oxygen and sulfur dioxide at 450 °C and 1-2 atm in the presence of the catalyst vanadium pentoxide:

$$2\ SO_{2(g)} + O_{2(g)} \rightleftharpoons 2\ SO_{3(g)}\ \Delta H = -197\ kJ{\cdot}mol^{-1} \quad (1)$$

The sulfur trioxide formed is added to sulfuric acid, giving rise to oleum (disulfuric acid):

$$H_2SO_4\ (l) + SO_3\ (g) \rightarrow H_2S_2O_7\ (l) \qquad (2)$$

The oleum is then added to water to form sulfuric acid, which is very concentrated:

$$H_2S_2O_7\ (l) + H_2O\ (l) \rightarrow 2\ H_2SO_4\ (l) \qquad (3)$$

It is important to specify that directly dissolving $SO_3$ in water is impractical due to the highly exothermic nature of the reaction. Acidic vapor or mists are formed instead of a liquid. The game depicted here is a simplified version of the process, focusing on reaction (1), occurring in a gas-solid packed bed (reactor I), and reactions (2) & (3), occurring in a bubbly column (reactor II). A water heat exchanger and the catalyst tank are also depicted in the simplified process flowsheet (Fig. 1. a).

## PRINCIPLE & OBJECTIVES

Each player is at the head of a chemical company, which must produce as much sulfuric acid (the molecule the most produced in the world - $H_2SO_4$) as possible and earn as much money as possible. It will be necessary to use the available resources to optimize the operation of the chemical process (the "contact" process). There are three versions of the game: 1-99 players, 2-4 players, with interaction and blocking between players, and the "advanced chemistry" version. The main objective of the first two versions is to introduce a chemical engineering flowsheet and give the student an initial idea of the several unit operations occurring in the process. The explanation of the rules will give details about the reaction or the operating conditions, and manipulating the reaction will help the student to learn about the process. The third version is adapted for practicing stoichiometric ratios in chemical reactions.

## RULES FOR 1-99 PLAYERS

This first mode is the classical way to play the game; it can be played solo, in small groups or for the whole class. The game starts with an introduction to the historical background by the teacher: "*In 1850, each player inherits a temporary the patent for the "Contact process", invented by Peregrine Phillips in 1831. Ownership of the patent will become permanent if the company you manage during the next year is the most effective and richest.*" Each colored dice represents a molecule: the blue is sulfur gas, the red is oxygen, the white is water and the yellow is the catalyst (an oxide of vanadium). The game lasts for 20 rounds, in each of which the four dice are thrown and each player must choose one to use on his game sheet. Once all the players have chosen their action, the round is marked on the top of the paper sheet. The next round starts and the game continues until the end of the round track is reached.

Blue and red dice are reactants that must be used to perform reactions in both reactors I and II. In reactor I, the player must necessarily combine a red dice and a blue dice of the same value, automatically creating a violet dice of the same value after the arrow in reactor I, and transfer it to reactor II. In the second reactor, the player must combine a violet dice (from reactor I) and a white dice of the same value, automatically creating sulfuric acid, which is sold for the same amount of money (dice value = dollar value). Figure 2 represents this combination of 3 dice of the same value creating the acid through the 3 chemical reactions (1, 2 & 3).

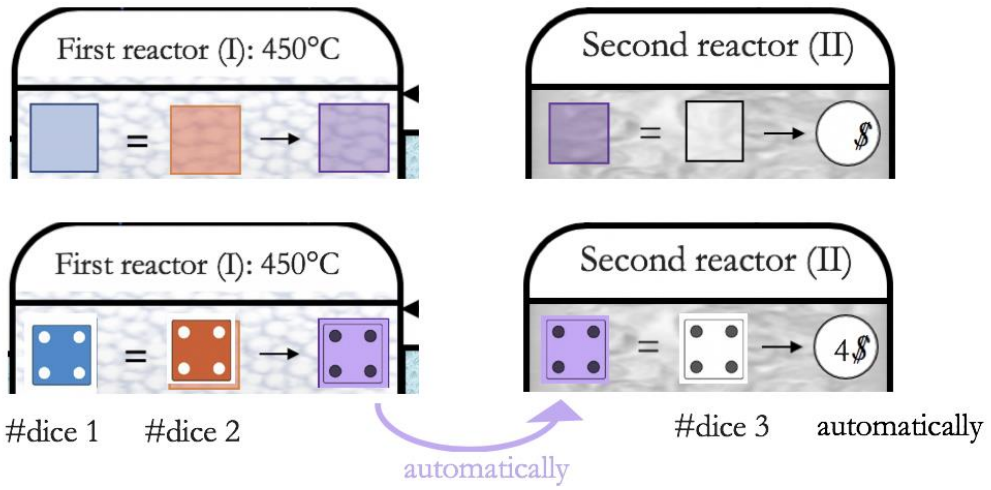



Figure 2. An example of dice combination to illustrate the principle of the game.

There is no order in which the reactants must be brought in (e.g. a white dice can be placed in reactor II before a violet dice has been obtained). However, once the reaction line is started in a reactor, the value of that line cannot be changed.

White dice do not just represent water as a reactant; they also represent the water that can be used to keep the first reactor at a constant temperature and thus improve the chemical reaction. Different combinations of numbers are to be made (two-way series, brelans or full houses) to improve the chemical reaction. Thus, the yield of the first reaction can be increased by plus or minus 1, 2 or 3 depending on the difficulty of the combination. These bonuses are permanent and cumulative. Finally, the water can be sold for one dollar per half value of the dice, but only once during the game.

The yellow dice are catalysts and do not react but they nevertheless accelerate the reaction and make it more efficient. Different combinations of numbers have to be achieved (from two or three sequences, double pairs or a square) in order to be able to modify the value of all a player's dice by 1, 2 or 3 during the phase of choice, or to change the color of the dice (for the square combination). These bonuses are permanent and cumulative. Finally, the catalyst can be sold at a third of the value of the dice alone, only once during the game.

Twice in the game, a player can go to the market and buy an improvement of his dice:

- for two dollars, he can turn it into a dice of the value of his choice,
- for one dollar, he can transform it into a dice of the value of his choice lower than 4,

Finally, players can also buy stocks on the stock exchange, investing their resources to form a series from 1 to 6 of any chosen color. If this series is complete at the end of the game, the player wins 6 dollars.

Once the 20 rounds are completed, each player counts his money earned by producing the sulfuric acid, on the stock exchange, and from the sale of resources, and deducts the money spent at the market. The richest player wins the game. In case of a tie, the player with the most reactions (I + II) wins and, in case of a further tie, the players share the victory.

## RULES FOR 2-4 PLAYERS

The second mode is a version for a limited number of players, from 2 to 4, with a major difference: the choice of the dice is made clockwise, and no longer simultaneously, and when a dice has been chosen it cannot be taken again during the round (with 2 players, each player must take a second dice). In this mode, a specific player sheet is used (see supplementary material page 2), on which the round marker is removed and two specific zones are added, offering a solution in case of blocking (impossibility to play). The first one is in reactor I, where the player can combine a series of 3 dice of reactants (blue or red) in order to produce a violet dice; this operation refers to the excess reactants. In case of blockage (i.e., the player cannot or does not want to use his dice elsewhere) he can put it in the black hole (Fig 3.b). This action is free for the first dice, but costs a penalty thereafter, and even loses the game after 6 dice.

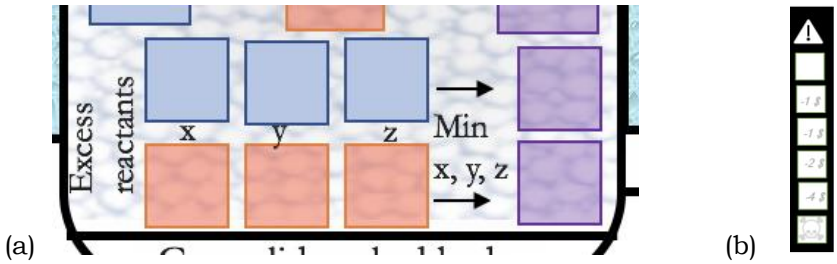



Figure 3. (a) The excess reactant zones. (b) The black hole module: An optional module to give the dice a color.

In this mode, the game lasts until a player has filled the 5 lines of his second reactor (II). Then the game is immediately stopped, and each player counts his points (even players who may have been eliminated) with the same rules as in the previous mode, taking account of the black hole.

## ADVANCED RULES

Here, a last version of the game is proposed. In this mode, instead of combining dice of the same values, the player has to combine dice and follow the stochiometric rules of each reaction (1-2 ratio for reactor I and 1-1 ratio for reactor II). Non-integer numbers are authorized and rounded to 1 number after the decimal point. Any excess reactant is lost immediately. For example, a combination of a value 5 blue dice and a value 6 red dice leads to a violet dice of value 2.5, the extra 1 value of red is lost. This advanced mode can be played with the two previous versions: 1-99 and 2-4 players with the

specific scoresheet (the marker "=" is replaced by the marker "+", see supplementary material pages 3&4) and the respective rules of dice choice.

## RESPONSES TO THE GAME AND DISCUSSION

Finally, when all students have finished playing the game, solo, by groups of 4, or with the whole class, a debriefing session will highlight the key elements of the chemistry necessary for the construction of this process and the educator will indicate the resources for further investigation after the class. A game stimulates students to discover scientific concepts in a playful way and gives them the opportunity to develop the adaptive and responsive skills that are expected of every student. Instead of listening to lectures or completing assigned reading and writing tasks, students are immersed in a story and given an opportunity to accomplish a fictional objective within a given time limit. It is also a chance for them to compete with, and against, their classmates, show off their individual skills, interact with each other, and experience moments of discovery and wins. This game is also a good activity to illustrate chemistry, and the process of making sulfuric acid. It lets the students play but also makes them manipulate chemical objects and concepts, such as reactor, catalyst, or simple chemical engineering flowsheet. The game does not require a chemistry background and can be used in courses before $9^{th}$ grade as an introduction to chemistry and an illustration of an application. As a learning tool, the advanced mode is a perfect way to practice stoichiometric ratios for $10\text{-}12^{th}$ grade and college courses. This game does not replace classical lectures but it is a complementary tool that can be used punctually and following the specific classes to take a break and to avoid monotony in the classroom.

The game has been tested on 50 students and volunteers, and several teachers from university and high-school. A survey form was completed by students and teachers in France and showed that 92% of the survey panel thought the game was suitable to develop manipulation of chemical concepts and was a good tool for increasing motivation (93%); 69% of the panel thought the game helped the students to be more active than in a traditional classroom. Finally, 90% of the panel enjoyed the experience and recommended this activity for use in the classroom. This game could be applied not only to sulfuric acid production, but to many different reactions found in chemical engineering.

## CONCLUSION

An original learning and practicing tool is proposed in this paper, based on a “roll&write” game. The game is a simple and inexpensive activity to help students to manipulate simple chemistry concepts such as multiple reactions, reactors, catalyst and heat exchanger. Many principles of thermodynamics or physics can be brought into focus when explaining the game rules. Then the game provides a complementary teaching method and helps the students to associate the basic concepts of chemistry with simple dice combinations in an immersive and entertaining environment. After getting to know the basic background of the game, students are involved in a score challenge, playing solo or with others, and can actually practice their chemistry knowledge for this purpose. Students are more active than in a traditional classroom, and apply and learn chemistry with pleasure and motivation. The game can be used as a refreshing tool to increase motivation in the classroom but also as a method for discovering a specific chemical engineering process, the basics of chemical engineering and its history. This game is relatively quick to organize, inexpensive (only 1 sheet of paper for 3 players, 4 dice and pencils) and brings really stimulating benefits.

## ASSOCIATED CONTENT

### Supporting Information

Full scoresheet for all versions (1-99 and 2-4 players and advanced version) and the optional dice modules.

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