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Mathematical Modeling as Strategy for Teaching Blood Bank Topics

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Abstract: **Didactic strategies are groups of activities and procedures, which once integrated provide a logical sequence to accomplish educational objectives. These strategies becoming transcendental within interdisciplinarity in superior education. Therefore, the use of mathematical models for teaching blood bank subjects topics allows linking the theory of transfusion science with mathematics, supporting student's conceptualizations and placing mathematics as a tool to describe and understand daily life and professional situations. Five models are presented for advanced blood banking courses, accomplishing the simulation, evaluation and prediction of blood unit's requests and storage, as well as decision making in transfusion techniques protocols.**

Keywords: **Blood bank – mathematical modelling – Technology – Didactic strategy.**

I. INTRODUCTION

Didactic strategies are groups of activities and procedures which once integrated provide a logical sequence to accomplish educational objectives. One of the most important challenges to education for current and upcoming generations is the diversity of emerging tendencies and new approaches to different topics, in response to this changes arises the need of better academically qualified professors. Particularly in mathematics since this discipline promotes skills of great significance in daily living as logic reasoning and creativity. This highlights the importance of introducing novel strategies which could help the student to recognize mathematics as an applicable discipline, and discouraging the misconception that mathematics is only a theoretical subject [1]. For this reason the incorporation of mathematics in courses of diverse nature like medical sciences could facilitate decision-making through the resultant prediction of models. Blood banking is a discipline which could take advantage of the use of mathematical models, more precisely it would contribute in the management of blood units and transfusion protocols.

II. MATHEMATICAL MODEL BASED TEACHING

Mathematical modeling is the activity of representing, manipulating and communicating natural phenomena through formulas and mathematical content that could permit the simulation of complex processes that allows the generation of hypothesis that can be validated through experimentation [2].

Mathematical models in blood banking are the link between the course contents and mathematics, in this manner, mathematics learning will give cognitive support to students conceptualizations [3]. Modeling not only produces mathematical representations of particular situations but incorporates other complex aspects of the phenomena as well [4].

Modeling has its basis in the scientific activity of the mathematician, applying and constructing models to explain phenomena, solving problems or generating knowledge in other subjects. Nevertheless, in education it is promoted the construction and interpretation of models with the objective of creating a meaningful mathematical concept, and with the intention of motivating students to gain interest for mathematics due to the connection mathematics has with the student's context [5]. In blood banks, these activities are oriented to decision making in donor recruitment systems, blood unit management, or the technical management of transfusion protocols.

Mathematical modeling in education has a pedagogical objective and two different tendencies can be recognized. One in which models are used to structure or promote the learning process of the students, and the other one considered of conceptual nature using the models to introduce and develop new concepts. Other perspectives consider the modeling as a cognitive process for analyzing of mental processes occurring during their execution [6].

One way to accomplish the contextualization of knowledge is the presentation of real cases that could to be represented through mathematical models to answer specific questions in real situations when a decision has to be made or a when it is imperative to make predictions related with social or natural phenomena [6].

Problem resolution as a pedagogic strategy can be associated with real situations where the identification, use and construction of models could be important in the learning experience [1]. Thereby, the student will discover the benefits of mathematics to deal and solve real problems and consequently make interpretations through mathematical results [7]. A numerical result lacks of value in absence of an appropriate context, it is mandatory to consider the imposed conditions by the situation [8]. Thus, from a didactic point of view, is important that the modelling perspective puts problem resolution in real context and incorporate non mathematical problems [9].

Mathematical models have been widely used in other areas like engineering, in contrast with the scarce use of them in medical sciences. Using mathematical models in higher education to solve specific problems allows students to face educational experiences not only integrating previously acquired knowledge but also deepen and propose new forms of education (Mora, 2012). The possibility of representing a problem, decision making, generating and verifying hypothesis and finally give interpretations in a given context are all advantages of using mathematical modeling. In summary, it favors cooperative and independent learning as well as the development of attitudes and skills related with decision making and peer interaction (Villalobos et al., 2012).

Mathematical modeling allows students to develop skills to visualize the context and the respective mathematical formulation in a parallel manner, it also shows the value of mathematics, as a pertinent, meaningful and practical science, and finally it enables the validation of solutions attending the theory and the contextual situation [10].

In the blood banking course, the use of information and communication technology (ICT) favors modeling due to the possibility of using, visualizing, creating, simulating and manipulating the models through specialized software, this emphasizes the interpretation using mathematical concepts and offers the possibility of studying high algebraic complexity examples.

Furthermore, the use of new technologies could help creating proof of concept models, obtaining different representation and experimentation modes and establish interpolations and extrapolations which are unobtainable through the context [10].

III. METHODS AND RESULTS: BLOOD BANKING MATHEMATICAL MODEL EXAMPLES

These examples were presented in two sessions of the course *Advanced methods in blood banking.* This course is part of the Immunohematology and Blood Banking Medical Specialty imparted at the University of Costa Rica.

Minimum stock linear models:

This example proposes probability distribution analysis as a manner to estimate the minimum product in stock and the time to offer a service, in our case, units for transfusion. A shortage in blood transfusion units in stock compromises medical attention, and creates a temporal imbalance between blood units supply and demand. Hence, blood banks must maintain a minimum stock that can be estimated from the daily request frequencies obtained from historical records. Two different models have been proposed [11], [12]:

Buch Model

$N = RU * LF + 3$

Fano & Longres Model

$N = RU * LF + 2*SD$

In which:

N : Group i blood units optimum number to maintain per day.

RU: Mean of group i blood units required per day.

LF: Local group i frequency.

SD: Standard deviation of group i blood units required per day.

Both models incorporate as a key element the interaction between the mean of group *i* blood units required per day and the local group *i* frequency. But differ in the residual units factor (assuming interaction as zero). The number three in the *Buch model* comes from the supposition that in an emergency three blood units will be required.

In the *Fano & Longres* model two standard deviations are considered for a 95% coverage factor.

TABLE I: EXAMPLE OF THE OPTIMAL MINIMUM STOCK OF BLOOD UNITS IN A BLOOD BANK

Group	Daily required blood units		Group frequency	Minimum stock	
	Mean	Standard deviation		*Buch Model*	*Fano & Longres Model*
A+	6.38	4.21	0.32	5.04	10.46
B+	2.07	2.2	0.11	3.23	4.63
AB+	0.28	0.68	0.03	3.01	1.37
O+	8.35	4.665	0.43	6.59	12.92
A-	0.67	1.08	0.03	3.02	2.18
B-	0.23	0.73	0.01	3.00	1.46
AB-	0.06	0.335	0	3.00	0.67
O-	0.81	1.225	0.06	3.05	2.50

Binomial distribution in waiting lines:

Waiting lines are the sequence of requests waiting for a blood unit, which contemplates the mobilization between shelves, pretransfusional testing and delivery of blood units. Employing a binomial distribution for discrete variables, the probability of "n" transfusion requests delivered in a "T" time frame can be estimated using the "λ" global blood units requests mean per time frame [12]:

$$P(n) = \frac{(\lambda T)^n}{n!} e^{-\lambda T}$$

For example, if one day the transfusion requests mean for a specific blood group is of 6.38, the probability of "n" expected requests for any other day is shown in Table 2.

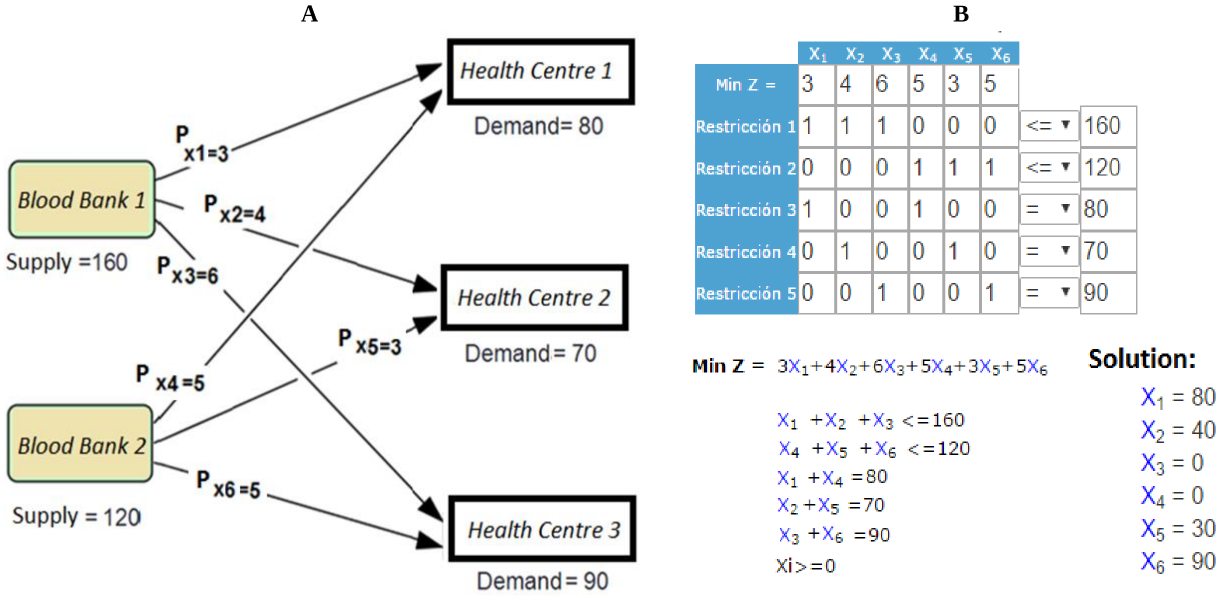
TABLE II. EXAMPLE OF BINOMIAL PROBABILITY DISTRIBUTION IN A CASE OF WAITING LINES IN A BLOOD BANK

n: expected requests	Probability P(n)	Percentage
1	0.0108	1.08
2	0.0345	3.45
3	0.0734	7.34
4	0.1170	11.70
5	0.1493	14.93
6	0.1588	15.88
7	0.1447	14.47
8	0.1154	11.54
9	0.0818	8.18
10	0.0522	5.22

Linear programming for blood unit distribution:

Linear programming is the field of mathematical optimization dedicated to optimize linear functions which are subject to restrictions expressed through linear inequation systems. In blood banking, blood unit's distribution policies aim to appropriately supply health centres requirements, determined by the blood unit production capacity of blood banks. The production is limited by the amount of blood donors, pretransfusional testing of blood, storage and shelf life of blood units.

For example, if we consider two blood banks capable of producing 120 and 160 blood units respectively and three health centers which require 80, 70 and 90 blood units. Thus, a linear function can be established to model the total cost of fulfilling those necessities taking into account the production restrictions and shipping costs. In result, we obtain the optimum blood unit distribution to minimize global costs.



Price per route: $P_{X\,i}$

Figure 1. Linear programming distribution model example

The solution can be obtained using computing platforms like Microsoft Excel. According to the previous graph the first blood bank could provide 80 units to health centre 1 and 40 units to health centre 2, and the other blood bank could provide 30 units to health centre 2 and 90 units to health centre 3.

With this distribution protocol, all health centers get the required blood unit supply in accordance to the operational capacity of both blood banks of producing ready to use blood units.

Differential equations dynamical models for plasmapheresis:

Mass action kinetics law states that the change of a substance quantity is proportional to the transient quantity of that particular substance, this can be mathematically stated as an initial value problem: $y'(t) = k\,y(t)$ where $y(0) = y_0$, and y(t) is the transient substance concentration, k is the proportionality constant and y_0 the initial concentration value. The previous equation has a solution defined by a exponential function: $y(t) = y_0\, e^{kt}$, this equation can be used to simulate molecule's movement in dynamical systems and the concentration change in a specific compartment.

In a therapeutical apheresis the change in the blood concentration of a substance is proportional to the transient concentration of that specific substance. Through experimentation it has been verified that the proportionality constant is -0.02 and the initial concentration value is 102 ng/dL, so the concentration after 10 minutes is: $y(10) = 102\, e^{-0.02 * 10} = 83.51$ ng/dL.

Nevertheless, a more complex model can be made considering other compartments and not only blood, an approach of interconnected tanks based in differential equations is capable of modeling the other compartments involved in the interchange dynamics. For example, using mathematical modeling software, a plasmapheresis system representation can be made [13].

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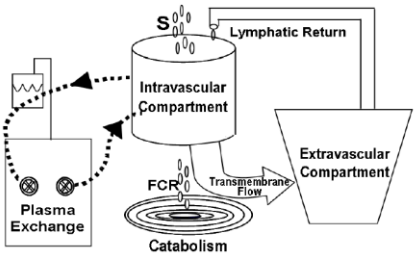
A



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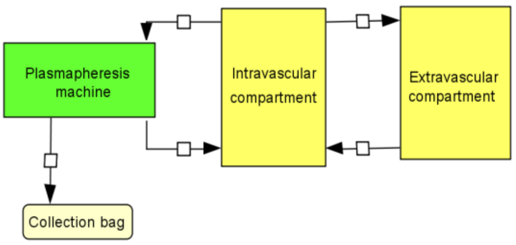

C

$$\frac{d\left(\left[\text{"Collection bag"}\right]\cdot V_{default}\right)}{dt} = +V_{default}\cdot\left(\frac{\left[\text{"Plasmapheresis machine"}\right]\cdot k2_{(re2)}}{V_{default}}\right)$$

$$\frac{d\left(\left[\text{"Plasmapheresis machine"}\right]\cdot V_{default}\right)}{dt} = -V_{default}\cdot\left(\frac{\left[\text{"Plasmapheresis machine"}\right]\cdot k2_{(re2)}}{V_{default}}\right) + V_{default}\cdot\left(\frac{\left[\text{"Intravascular compartment"}\right]\cdot k1_{(re9)}}{V_{default}}\right) - V_{default}\cdot\left(\frac{\left[\text{"Plasmapheresis machine"}\right]\cdot k1_{(re10)}}{V_{default}}\right)$$

$$\frac{d\left(\left[\text{"Intravascular compartment"}\right]\cdot V_{default}\right)}{dt} = -V_{default}\cdot\left(\frac{\left[\text{"Intravascular compartment"}\right]\cdot k1_{(re7)}}{V_{default}}\right) + V_{default}\cdot\left(\frac{\left[\text{"Extravascular compartment"}\right]\cdot k1_{(re8)}}{V_{default}}\right) - V_{default}\cdot\left(\frac{\left[\text{"Intravascular compartment"}\right]\cdot k1_{(re9)}}{V_{default}}\right) + V_{default}\cdot\left(\frac{\left[\text{"Plasmapheresis machine"}\right]\cdot k1_{(re10)}}{V_{default}}\right)$$

$$\frac{d\left(\left[\text{"Extravascular compartment"}\right]\cdot V_{default}\right)}{dt} = +V_{default}\cdot\left(\frac{\left[\text{"Intravascular compartment"}\right]\cdot k1_{(re7)}}{V_{default}}\right) - V_{default}\cdot\left(\frac{\left[\text{"Extravascular compartment"}\right]\cdot k1_{(re8)}}{V_{default}}\right)$$

D

time / names	s2	s3	s5	s6
0.0	0.0	0.0	10.0	102.0
0.1	6.98971158...	0.29452818...	10.0	87.9369922...
0.2	12.0052998...	1.06582386...	10.0	76.3919287...
0.3	15.5051019...	2.17504494...	10.0	66.8646612...
0.4	17.8467946...	3.51583130...	10.0	58.9589168...
0.5	19.3091223...	5.00714443...	10.0	52.3603219...
0.6	20.1089130...	6.58767160...	10.0	46.8191591...
0.7	20.4144798...	8.21142871...	10.0	42.1367541...
0.8	20.3561548...	9.84431399...	10.0	38.1547483...
0.9	20.0345457...	11.4614154...	10.0	34.7466619...
1.0	19.5270297...	13.0449017...	10.0	31.8112351...
1.1	18.8928425...	14.5823764...	10.0	29.2671855...
1.2	18.1770682...	16.0655953...	10.0	27.0490776...
1.3	17.4137956...	17.4894577...	10.0	25.1040356...
1.4	16.6285643...	18.8512312...	10.0	23.3891773...
1.5	15.8402653...	20.1499554...	10.0	21.8696028...
1.6	15.0626683...	21.3859663...	10.0	20.5167640...
1.7	14.3056001...	22.5605358...	10.0	19.3071921...
1.8	13.5758587...	23.6755955...	10.0	18.2214959...
1.9	12.8779307...	24.7335249...	10.0	17.2435637...
2.0	12.2145539...	25.7369884...	10.0	16.3599266...
2.1	11.5871490...	26.6888147...	10.0	15.5592577...
2.2	10.9961570...	27.5919048...	10.0	14.8319713...
2.3	10.4413018...	28.4491646...	10.0	14.1699023...
2.4	9.92178926...	29.2634564...	10.0	13.5660521...
2.5	9.43646203...	30.0375636...	10.0	13.0143851...
2.6	8.98391879...	30.7741667...	10.0	12.5096622...
2.7	8.56260717...	31.4758265...	10.0	12.0473059...
2.8	8.17088813...	32.1449756...	10.0	11.6232966...
2.9	7.80708414...	32.7839144...	10.0	11.2340882...
3.0	7.46951739...	33.3948094...	10.0	10.8765369...

S2: Plasmapheresis machine; S3: collection bag;

S5: Extracellular compartment; S4: intracellular compartment

E

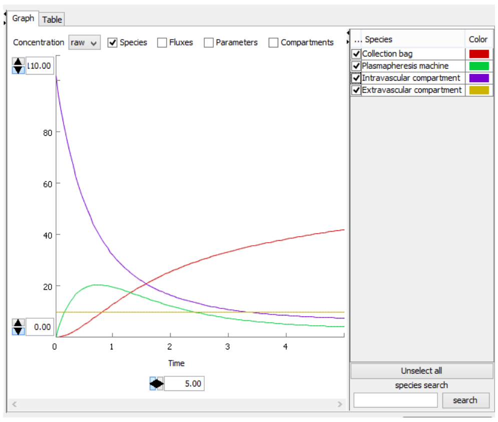

Figure 2. Example of the application of interconnected tanks and differential equations dynamical models in therapeutic plasmapheresis

Each compartment of the plasmapheresis system (2-A) is represented schematically as an interconnected tank (2-B) with an integrated differential equation system (2-C) to model the concentration changes in each compartment, achieving not just a numerical (2-D) but also a graphical simulation (2-E) for each compartment,

Using the previous model a simulation of a sustained plasmapheresis to a patient can be made: due to the exponential decrease (purple line), the effectiveness of the process decreases through time, this highlights the importance of the initial plasmapheresis phase in which the best effectiveness is achieved.

Differential equations dynamical models for permissible blood loss:

Permissible blood loss is the maximum blood volume a patient can loss before a significant intervention has to be made to replenish bodily blood volume, thus, the critical moment when a transfusion is needed during surgery can be determined [14]. Analogously to the previous example, the differential equation may be constructed in the following manner:

$$\frac{dHt}{dVp} = -\frac{Ht}{Vst} \quad \text{where} \quad Ht(0) = Ht_0$$

Where *Ht* represents hematocrit through time, Ht_0 the initial hematocrit, *Hf* the final hematocrit, *Vpt* the total lost volume and *Vst* the total blood volume. The solution of the previous equation is:

$$Hf = Ht_0\, e^{-\frac{Vpt}{Vst}}$$

Consider a patient undergoing surgery with 14.3 g/dL hemoglobin and 45.0 % hematocrit (preoperatory results) and an estimated total blood volume of 5.6 L. If during surgery the patient has lost 1.2 L of blood the hematocrit in that moment would be: $45.0\ e^{-1.2/5.6}$ = 36.32 %.

Presented examples works as motivational axis for the incorporation of mathematical modeling into operational management and technical decision making in the blood bank. Beyond academic exercise, predictions about the availability of blood units and the waiting line, or their distribution, can be used to make decisions regarding the handling and use of the bags. On the other hand, dynamic models collaborate to understand concepts related to plasmapheresis, the effect of prolonged procedures and effectiveness, as well as critical decisions regarding when to transfuse.

IV. CONCLUSION

Mathematical modeling pretends to give interpretations and predictions to different conditions whichconditions, which motivates students to face different situations like decision-making, autonomy development, critical thinking, collaborative attitudes, professional skills and self-evaluation capacity.

The presented models were implemented in an advanced blood banking course in the medical blood banking specialty offered in the University of Costa Rica. Mathematical modeling offers the possibility to link together professional practice and in silico simulations using a suitable language, exaltation of competences, decision making and development of critical skills to determine the suitability and limitation of the models. The affective and emotional attitude that must be developed in the university courses must include learning experiences that motivate the students, in which the interrelation of academic areas is achieved and the understanding is enhanced thanks to the inference, modeling, simulation and contrast of predictions.

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