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Research Article

Development of the RCUSP Model for the Purpose of improving the Curriculum Evaluation

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ABSTRACT

The current study presents the development of the new curriculum evaluation model, that resulted from improving the previously developed model called Susceptible-vaccinated-healthy-infected-recovered (SVHIR) model. The previous model was presented as an exploratory study, which means it was a study open for improvement. In the new model the compartments categorization would more relevant to the context of teaching and learning than of the previous model, since it does not categorize students who lack High order thinking skilled (HOTS) as being sick. Also, the basic mathematical details that were omitted in the previous model, are now included to enable a better model understanding by a reader. Further on, the current study elaborates the importance of the evaluation model and some parameters such as reproductive ratio. It is also discovered that the newly developed model is not limited only to HOTS, but is open a wider range of curriculums and skills. Lastly, the new model is found to be simpler than the previous model, given it has less compartments to be predicted. Hence, it is more accessible to any reader for better understanding and application.

Keywords: Model, HOTS, SVHIR, Curriculum and Compartment

INTRODUCTION

The idea of evaluation is not a modern approach, since as early as 2200 B.C. this idea existed. The public officials of Chinese emperors were required to show proficiency in formal tests during that time, which was and still is a form of evaluation [1]. It was between the years 1930 and 1960 when curriculum evaluation was noticed to mostly involve a variety of evidence on student performance and program effectiveness [2 -12]. Currently, Mazibuko and Maharaj [13] proposed a mathematical model to evaluate HOTS in the mathematics curriculum operating in Technical and Vocational Education and Training (TVET) colleges of South Africa. Their model derives from SIR (Susceptible S(t), Infected I(t) and recovered R(t)) model and it is called SVHIR model. The HOTS evaluation model is useful, especial if the primary objective of the curriculum is to equip students with HOTS; where the curriculum can be evaluated without wasting more time and resources. There were instances in South Africa where the curriculum was found to not serve the purpose after many years of its operation, and at that point already significant time and resources were invested for the implementation of the curriculum.

One of the instances was in the year of 1998, where an outcome-based-education (OBE) was introduced and seven years later it was discontinued because it was unsuccessful [12]. In that case, the SVHIR Model would have been the right tool for evaluating the OBE in the early years of its operation, if its primary aim was to equip students with HOTS. The SVHIR model is meant to predict the effectiveness of the curriculum to equip individuals with HOTS at the early stages of the curriculum operation. However, it cannot be ignored that the model is still on the developmental stages and it has not served the purpose yet, hence it is open for improvement. Firstly, the SVHIR Model categorizes students who lack HOTS as sick.

It is understandable that the model derives from an epidemiological model (SIR model) and there are circumstances that led the pioneers of the SVHIR Model to present students as sick. Nonetheless, it is still inappropriate to present students as sick and it can be improved. Secondly, the pioneers of the model mostly focused on the development of the model in the first publication and provided insufficient information about the significance of the model. A broader explanation on how the model will better teaching and learning is necessary, especially when the model is first introduced to the people.

Thirdly, in the first manuscript some of the model mathematics steps were omitted during the model development. Some readers may find themselves clueless about the model, especially when they have a limited mathematics knowledge. Therefore, that aspect was also opened for improvement, to allow more people to have access to the model. Fourthly, some important parameters such as the reproductive ratio are not clearly detailed for the reader to appreciate those parameters' involvement in the study.

Therefore, the current study aims to improve the SVHIR Model on the above four mentioned issues of the model. We therefore present the overall improved and simplified version of the SVHIR Model, which has the new name, receptive-curriculum content-unskilled-skilled-prior skilled (RCUSP).

METHODOLOGY

According to the current study there are three main components that can influence the outcome of equipping students with HOTS, as to whether the students get equipped or stay unequipped within the duration of a particular curriculum. Firstly, it is the content delivery. Under this component we include everything that could prevent or hinder the students from receiving the content such as incapable teachers/lecturers, lack of resources and an unproductive environment. Secondly, readiness of the students to receive the content. Under this component we include students who are going through personal challenges that makes it harder to concentrate, students who passed the lower grades undeservingly and they are not ready for the training of the current grade, and many more challenges regarding readiness of a student.

Thirdly, it is the curriculum content itself. This is where the selected topics for particular curriculum content are not mainly for HOTS equipping. In the case where the first two components (content delivery and student readiness) are found to be adequate, then the SVHIR Model become the right tool to evaluate the ability of curriculum content to equip students with HOTS refer to APPENDIX 1. This means the model can be used to evaluate a new curriculum. However, one can question the significance of the SVHIR Model since it can only evaluate the curriculum that is in operation. The SVHIR Model does not immediately avoid the problem but instead it avoids the problem from prolonging.

Given a new curriculum where HOTS is the primary objective, the SVHIR Model only needs the curriculum to operate for a short period of time to collect the data. Hence, derive the standardized model parameters and used the model to evaluate the ability of the curriculum to equip students with HOTS. With the SVHIR Model, a problem that would have taken twenty years to be identified could be identified in a much shorter time period.

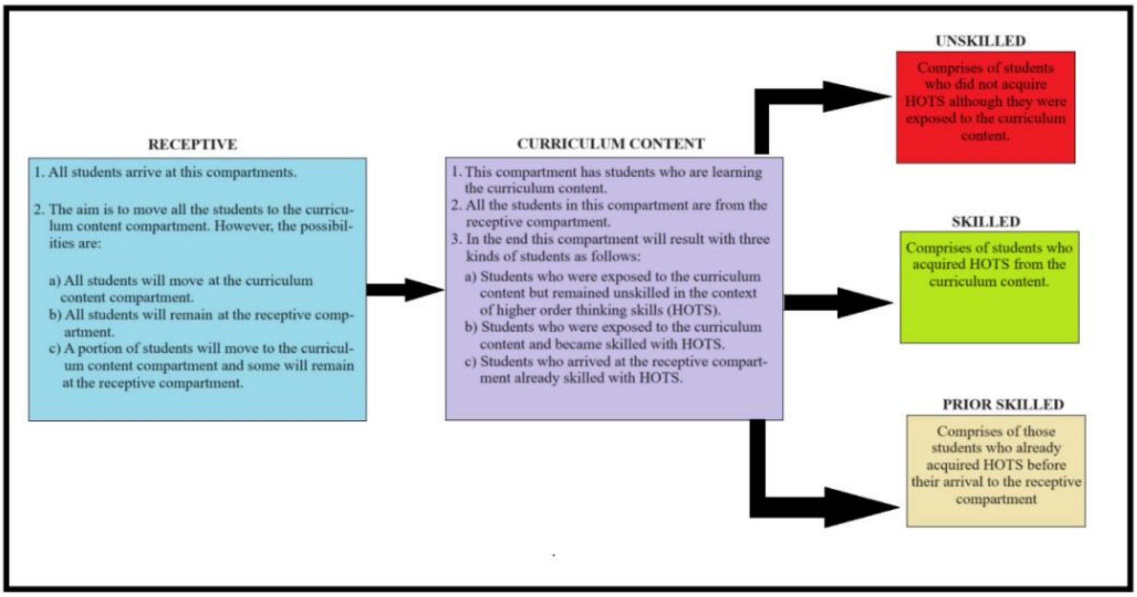
The current study improves the SVHIR Model and the same properties are still retained. In that regard, this section presents the development of the new model which results from the improvement of the SVHIR Model.

Model development

The new model consists of the five compartments namely receptive R(t), curriculum content C(t), unskilled U(t), skilled S(t), prior skilled P(t). Hence, the name of the new model abbreviates the compartments and it is called RCUSP model. The first compartment is receptive R(t), which is the stage where all the students first arrive before being exposed to the curriculum content. In this compartment, the fact is that a certain percentage of students might have previously acquired HOTS and some have not.

However, in the current study we neither consider them equipped nor unequipped but ready to learn the curriculum content. It is at the curriculum content C(t) stage where students begin to be taught the curriculum content. After the curriculum content stage students might move to the third compartment which is the unskilled U(t). These are students whom the curriculum could not equip with HOTS. Again, after the curriculum content students might move to the fourth compartment which is skilled S(t). These are students who are equipped with HOTS by the curriculum content in topic. Lastly, students might move to the fifth compartment which is prior skilled P(t). This is a percentage of students that had already acquired HOTS prior to the receptive compartment, which is prior to the learning of the curriculum content. For these students, the curriculum content in topic did not equip them with the adequate HOTS. This summary is also presented in Figure 1.

Figure 1: RCUSP Model compartments details

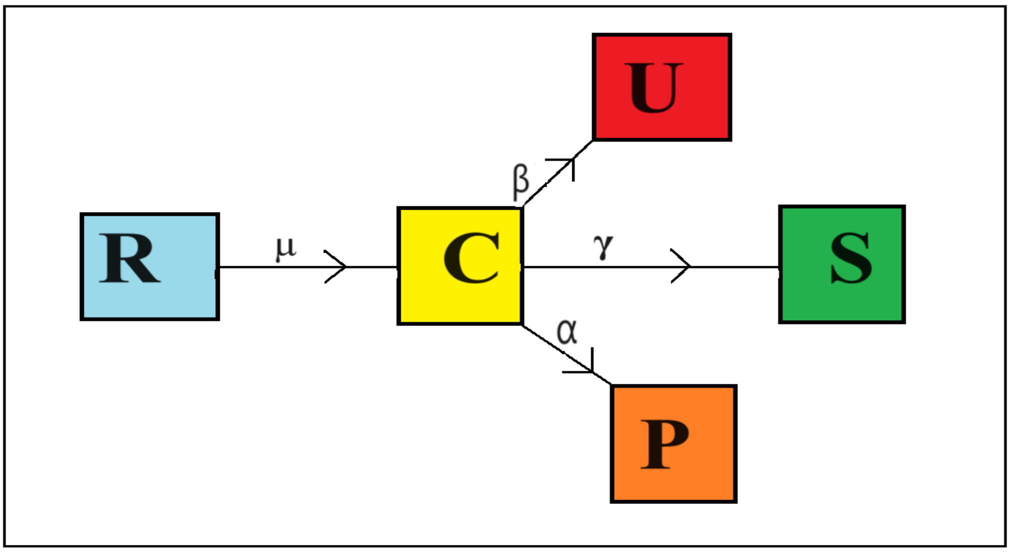


For the purpose of formulating differential equations for the RCUSP model, Figure 2 presents the compartments of the RCUSP model with the respective transition rates. The parameters μ , β , γ and α represents curriculum content transition rate, unskilled transition rate, skilled transition rate and prior skilled transition rate respectively. Equation (1) presents the compartments' rates change with respect to time.

The receptive compartment only loses students at a rate μ, hence the receptive rate of change $\left(\frac{dR}{dt}\right)$ is the negative of the curriculum content transition rate (μ) multiplied by receptive compartment which is a function of time in equation (1)(a). On the other hand, the unskilled, skilled and prior skilled compartment receives portions of students from the curriculum content compartment at a rate β, γ and α respectively. Therefore, the unskilled $\left(\frac{dU}{dt}\right)$, skilled $\left(\frac{dS}{dt}\right)$ and prior skilled $\left(\frac{dP}{dt}\right)$ rates of change are the positive of the unskilled (β), skilled (γ) and prior skilled (α) transition rates respectively; multiplied by the respective portions of curriculum content compartment which is a function of time in equation (1)(b), (1)(c) and (1)(d). Notice that there is no differential equation for the curriculum content.

When the differential equations are integrated they become the compartment prediction equations. However, in the current study the prediction of the curriculum content compartment is insignificant. Therefore, we excluded the formulation of curriculum content compartment rate of change.

Figure 2: RCUSP Model with the transition rates.



The differential equations of the RCUSP model are given as follows:

$$\left.\begin{aligned} \frac{dR}{dt} &= -\mu R(t), && (a)\\ \frac{dU}{dt} &= \beta C(t), && (b)\\ \frac{dS}{dt} &= \gamma C(t), && (c)\\ \frac{dP}{dt} &= \alpha C(t). && (d) \end{aligned}\right\} \quad (1)$$

Integrating (1) will produce compartment prediction equations denoted by subscript p. Therefore from (1)(a) we get,

$$\frac{dR}{R} = -\mu dt, \quad (2)$$

$$\int \boldsymbol{\frac{dR}{R}} = -\boldsymbol{\mu} \int \boldsymbol{dt},$$

$$R_p(t) = c_1 e^{-\mu t}. \quad (3)$$

As explained above, all the students arrive at the receptive compartment. Also, the current study does not consider students that will register or deregister the course/subject at a later stage. Therefore, the receptive compartment has the total number of students (N) on day 1, hence $R_p(1) = N$. On the other hand, when we substitute $t = 1$ into (3) we get,

$$R_p(1) = Ne^{-\mu}.$$
$$N = c_1 e^{-\mu}$$
$$c_1 = Ne^{\mu} \quad (4)$$

Substituting (4) into (3) and eliminating c_1 we get,

$$R_p(t) = Ne^{\mu(1-t)}. \quad (5)$$

Dividing (1)(b) by (1)(a) we get,

$$\frac{dU}{dR} = -\frac{\beta C}{\mu}\frac{1}{R}, \quad (6)$$

$$\int dU = -\frac{\beta C}{\mu}\int \frac{dR}{R},$$

$$U_p(t) = -\frac{\beta C}{\mu} lnR_p + c_2. \quad (7)$$

From (7),

$$c_2 = \frac{\beta C}{\mu} lnR_p + U_p(t). \quad (8)$$

Therefore,

$$c_2 \geq \frac{\beta C}{\mu} lnR_p. \quad (9)$$

Dividing (1)(c) by (1)(b) we get,

$$\frac{dS}{dU} = \frac{\gamma}{\beta}, \quad (10)$$

From (10) we get,

$$\int dS = \frac{\gamma}{\beta}\int dU$$

$$S_p(t) = \frac{\gamma}{\beta} U_p(t) + c_3{}^*$$

$$S_p(t) = -\frac{\gamma C}{\mu} lnR_p + c_3 \quad where \quad U_p(t) = -\frac{\beta C}{\mu} lnR_p + c_2 \tag{11}$$

Equation (11) implies that,

$$c_3 \geq \frac{\gamma C}{\mu} lnR_p \, . \tag{12}$$

Dividing (1)(d) by (1)(b) we get,

$$\frac{dP}{dU} = \frac{\alpha}{\beta} \, . \tag{13}$$

$$P_p(t) = -\frac{\alpha C}{\mu} lnR_p + c_4 \quad where \quad U_p(t) = -\frac{\beta C}{\mu} lnR_p + c_2 \tag{14}$$

Equation (14) implies that,

$$c_4 \geq \frac{\alpha C}{\mu} lnR_p \, . \tag{15}$$

The resulted compartment prediction equations from integrating the model differential equations from (2) to (15), are as follows:

$$\left.\begin{aligned}
&R_p(t) = c_1 e^{-\mu t} \quad where \;\; c_1 = Ne^{-\mu} \, , \\
&U_p(t) = -\frac{\beta C}{\mu} lnR_p + c_2 \quad where \quad c_2 \geq \frac{\beta C}{\mu} lnR_p \, , \\
&S_p(t) = -\frac{\gamma C}{\mu} lnR_p + c_3 \quad where \quad c_3 \geq \frac{\gamma C}{\mu} lnR_p \, , \\
&P_p(t) = -\frac{\alpha C}{\mu} lnR_p + c_4 \quad where \quad c_4 \geq \frac{\alpha C}{\mu} lnR_p \, .
\end{aligned}\right\} \tag{16}$$

The equations in (16) are useful for the validation of the RCUSP model and prediction of the compartments. However, the validation and compartment predictions cannot be computed without knowing the compartment transition rates (μ, β, γ and α).

The equations in (16) were produced by applying indefinite integrals, next we will apply the definite integrals on the same equations to obtain the compartment transition rates. The limits of the integrals are found from the actual data and their descriptions are given in Table 1. Note that in what follows, the subscript with respect to f refers to the final day.

For example, R_f refers to the number of individuals at the receptive compartment on the final day.

From (2) we get,

$$\int_{R_1}^{R_f} \frac{dR}{R} = -\mu \int_{t_1}^{t_f} dt. \tag{17}$$

Integrating and solving for μ in (17) we get,

$$\mu = \frac{lnR_f - lnR_1}{t_1 - t_f} \, . \tag{18}$$

From (6) we get,

$$\int_{U_1}^{U_f} dU = -\frac{\beta C}{\mu} \int_{R_1}^{R_f} \frac{dR}{R} \, . \tag{19}$$

Integrating in (19) and solving for β by using (18) we get,

$$\beta = \frac{U_f - U_1}{C(t_f - t_1)} \, . \tag{20}$$

From (10) we get,

$$\int_{S_1}^{S_f} dS = \frac{\gamma}{\beta} \int_{U_1}^{U_f} dU. \tag{21}$$

Integrating in (21) and solving for γ by using (20) we get,

$$\gamma = \frac{S_f - S_1}{C(t_f - t_1)}. \tag{22}$$

From (13) we get,

$$\int_{P_1}^{P_f} dP = \frac{\alpha}{\beta}\int_{U_1}^{U_f} dU. \tag{23}$$

Integrating (23) and solving for α by using (20) we get,

$$\alpha = \frac{P_f - P_1}{C(t_f - t_1)}. \tag{24}$$

Therefore, combining (18), (20), (22) and (24) we have:

$$\left.\begin{aligned} \mu &= \frac{lnR_f - lnR_1}{t_1 - t_f}, \\ \beta &= \frac{U_f - U_1}{C(t_f - t_1)}, \\ \gamma &= \frac{S_f - S_1}{C(t_f - t_1)}, \\ \alpha &= \frac{P_f - P_1}{C(t_f - t_1)}. \end{aligned}\right\} \tag{25}$$

One of the most vital parameters in the RCUSP model is the basic reproductive ratio (R_0) which has two cases as follows [13]:

Case 1: If $R_0 > 1$, this means the curriculum is incapable of equipping students with HOTS.
Case 2: If $R_0 < 1$, this means the curriculum is capable of equipping students with HOTS.

The basic reproductive ratio is mathematically expressed as:

$$R_0 = \frac{\beta}{\gamma}$$

$$R_0 = \frac{U_f - U_1}{S_f - S_1} \tag{26}$$

Table 1: RCUSP Model parameters and their descriptions.

Parameters	Description
μ	Curriculum content transition rate.
β	Unskilled transition rate.
γ	Skilled transition rate.
α	prior skilled transition rate.
t_1	Initial or 1st day.
t_f	Final day.
R_1	Number of individuals at the receptive compartment on the 1st day.
R_f	Number of individuals at the receptive compartment on the final day.
U_1	Number of individuals at the unskilled compartment on the 1st day.
U_f	Number of individuals at the receptive compartment on the final day.
S_1	Number of individuals at the skilled compartment on the 1st day.
S_f	Number of individuals at the skilled compartment on the final day.
P_1	Number of individuals at the prior skilled compartment on the 1st day.
P_f	Number of individuals at the prior skilled compartment on the final day.
N	Total number of individuals.

Table 2: Description and RCUSP compartmental categorization of students based on HOTS tests scores range.

Order	Scores	Description	Compartment
1	$0 \leq M_i \leq 5\%$	Nil	Receptive
2	$5\% < M_i < 50\%$	fail	Unskilled
3	$M_i \geq 50\%$	pass	Skilled or Prior skilled

Association of the Actual Data with the RCUSP Model

According to Tyler [2], educational evaluation should at least involve two appraisals, since one cannot draw a conclusion by only assessing students at the end of the program without knowing where they were at beginning of the program. Hence, the current study data collection instruments were two similar HOTS tests.

In this study we used the HOTS test scores or marks (M_i) to categorise students according to the RCUSP model compartments. However, before detailing the compartments, we first defined the tests scores ranges respectively as shown in *Table 2*. Note the following when interpreting the table:

1. A score less than or equal to 5% cannot be used to define the status of a student, it's a nil. Note that it is highly possible for such a score to be obtained by a person who guessed the answers without being exposed to the curriculum. Therefore, we equivalate this person as someone who never took the test, hence this score is associated with receptive compartment.
2. A student with a scored between 5% and 50% counts as a failed, hence this score is associated with unskilled compartment.
3. A student with a score of 50% and above counts as a pass, hence this score is associated with Skilled or Prior skilled compartment.

There are fifteen possible combination outcomes if a student takes the two HOTS tests and each outcome defines the RCUSP model compartment as shown in Table 3. In our endeavour to explain the fifteen combination outcomes the words receptive, skilled and unskilled refers to the compartments. Therefore, the outcomes are explained as follows:

1. A student who got nil in the first test and nil in the second test is considered to be in the receptive. The first test shows signs of receptive (neither skilled nor unskilled), towards the end of the curriculum the second test confirms the receptive sign remained the same. That means the student did not move to the curriculum content compartment, hence the student stays in the receptive compartment. Nonetheless, this does not mean the curriculum was not presented to the student but rather means it was presented and did not make any significant impact or sink to the student. Therefore, the student is at the same level as the time of arrival, which happens at the receptive stage.
2. A student who got nil in the first test and failed in the second test is considered unskilled. The first test shows the signs of receptive, towards the end of the curriculum the second test confirms that the student is unskilled. Hence the student will move from receptive R(t), curriculum content V(t) and to unskilled U(t) compartment. In this case, the curriculum was presented and did make an impact to the student but not enough to equip them.
3. A student who got nil in the first test and pass in the second test is considered skilled. The first test shows the signs of the receptive, towards the end of the curriculum the second test confirms the signs has improved. Hence the student will move from receptive R(t), curriculum content V(t) and to skilled S(t) compartment. This happens when the curriculum presented to such a student is much impactful.
4. A student who got fail in the first test and nil in the second test is considered unskilled. The first test show signs of unskilled, towards the end of the curriculum the second test confirms the signs of receptive. This student is considered unskilled. In the model this student will move from receptive R(t), curriculum content C(t) and to unskilled U(t) compartment. In this case, the curriculum was presented and did make an impact to the student, but not enough to equip students with HOTS.
5. A student who got fail in the first test and fail in the second test is considered unskilled. The first test shows the signs of unskilled, towards the end of the curriculum the second test confirms the signs remained the same. Hence the student will move from receptive R(t), curriculum content C(t) and to unskilled U(t) compartment. In this case, the curriculum was presented and did make an impact to the student but not enough to equip students with HOTS.
6. A student who got fail in the first test and pass in the second test is considered skilled. The first test shows the signs of unskilled, towards the end of the curriculum the second test confirms the signs has gotten better. Hence the student will move receptive R(t), curriculum content C(t) and to skilled S(t) compartment. In this case, the curriculum was presented and did make an impact to the student.
7. A student who got pass in the first test and nil in the second test is considered skilled. The first test shows the signs of prior skilled, towards the end of the curriculum the second test confirms the signs of the receptive. For a student to be from prior skilled to receptive, it is the indication of degradation of the skill; and that can only happen when someone is becoming unskilled. Hence the student will move from receptive R(t), curriculum content C(t) and to unskilled U(t) compartment. In this case, the curriculum was presented and did make an impact to the student but not enough.

8. A student who got pass in the first test and fail in the second test is considered infected. The first test shows the signs of prior skilled, towards the end of the curriculum the second test confirms the signs of unskilled. For a student to be from prior skilled to unskilled, it is the indication of degradation of the skill; and that can only happen when someone is becoming unskilled. Hence the student will move from receptive R(t), curriculum content C(t) and to unskilled U(t) compartment. In this case, the curriculum was presented and did make an impact to the student but not enough.
9. A student who got pass in the first test and pass in the second test is considered prior skilled. The first test shows the signs of prior skilled, towards the end of the curriculum the second test confirms the signs has remained the same. Hence the student will move from receptive R(t), curriculum content C(t) and to prior skilled P(t) compartment. This student is presumed to have arrived already equipped, hence when the curriculum is presented to them is much impactful.
10. A student who got nil in the first test and did not get a chance to participate in the second test, is excluded in the current study. The reason being, with the three possible scores (Nil, fail and pass) the student could have obtained in the second test, the student could either be outcome 1 or 2 or 3 in Table 3. Which are three different compartments (Receptive or Unskilled or Skilled) the student could possibly belong to and the study is unable to conclude about the student' compartment between the three in the absence of the second test score. Hence, the student is excluded.
11. A student who got fail in the first test and did not get a chance to participate in the second test, is excluded in the current study. The reason being, with the three possible scores (Nil, fail and pass) the student could have obtained in the second test, the student could either be outcome 4 or 5 or 6 in *Table 3*. Which are two different compartments (Unskilled or Skilled) the student could possibly belong to, and the study is unable to conclude about the student' compartment between the two in the absence of the second test score in that case. Hence, the student is excluded.
12. A student who got pass in the first test and did not get a chance to participate in the second test, is excluded in the current study. The reason being, with the three possible scores (Nil, fail and pass) the student could have obtained in the second test, the student could either be outcome 7 or 8 or 9 in *Table 3*. Which are two different compartments (Unskilled and prior skilled) the student could possibly belong to, and the study is unable to conclude about the student' compartment between the two in the absence of the second test score in that case. Hence, the student is excluded.
13. A student who did not participate in the first test and got nil in the second test, is excluded in the current study. The reason being, with the three possible scores (Nil, fail and pass) the student could have obtained in the first test, the student could either be outcome 1 or 4 or 7 in *Table 3*. Which are two different compartments (Receptive or Skilled) the student could possibly belong to, and the study is unable to conclude about the student' compartment between the two in the absence of the first test score in that case. Hence, the student is excluded.
14. A student who did not participate in the first test and get fail in the second test is considered unskilled. The reason being, with the three possible scores (Nil, fail and pass) the student could have obtained in the first test, the student could either be outcome 2 or 5 or 8 in *Table 3*. Which are all the unskilled compartments but it is excluded for this study since is without demography, which means the study does not consider students that will register or deregister the course/subject at a later stage.
15. Lastly, this is a student who only participated in the second test and passed. This student will also be excluded in the current study. The reason being, with the three possible scores (Nil, fail and pass) the student could have obtained in the first test, the student could either be outcome 3 or 6 or 9 in *Table 3*. Which are two different compartments (Skilled or Prior skilled) the student could possibly belong to, and the study is unable to conclude about the student' compartment between the two in the absence of the first test score in that case. Hence, the student is excluded.

Table 3: Compartmental categorization of students based on the two HOTS tests scores.

Outcome	Test 1 Marks ($t = Day\ 1$)	Test 2 Marks ($t = Final$)	Resultant Compartment ($t = Final$)
1	$0 \leq M_i \leq 5\%$	$0 \leq M_i \leq 5\%$	Receptive
2	$0 \leq M_i \leq 5\%$	$5\% < M_i < 50\%$	Unskilled
3	$0 \leq M_i \leq 5\%$	$M_i \geq 50\%$	Skilled
4	$5\% < M_i < 50\%$	$0 \leq M_i \leq 5\%$	Unskilled
5	$5\% < M_i < 50\%$	$5\% < M_i < 50\%$	Unskilled
6	$5\% < M_i < 50\%$	$M_i \geq 50\%$	Skilled
7	$M_i \geq 50\%$	$0 \leq M_i \leq 5\%$	Unskilled
8	$M_i \geq 50\%$	$5\% < M_i < 50\%$	Unskilled
9	$M_i \geq 50\%$	$M_i \geq 50\%$	Prior skilled
10	$0 \leq M_i \leq 5\%$	None	Excluded
11	$5\% < M_i < 50\%$	None	Excluded
12	$M_i \geq 50\%$	None	Excluded

13	None	$0 \leq M_i \leq 5\%$	Excluded
14	None	$5\% < M_i < 50\%$	Unskilled but excluded for this study
15	None	$M_i \geq 50\%$	Excluded

M_i – Student's HOTS Test Marks/score **t – Days*

RESULTS OF THE RESEARCH

The equations in (16) are the predictions of the four RCUSP model compartments namely receptive, unskilled, skilled and prior skilled; where the number of individuals in the curriculum content (C) is given. Therefore, combining equation (16) and (25) we get:

$$\left.\begin{aligned} R_p(t) &= c_1 e^{-\mu t} \quad where \quad c_1 = Ne^{-\mu}, \mu = \frac{lnR_f - lnR_1}{t_1 - t_f} \\ U_p(t) &= -\frac{\beta C}{\mu} lnR_p + c_2 \quad where \quad c_2 \geq \frac{\beta C}{\mu} lnR_p, \beta = \frac{U_f - U_1}{C(t_f - t_1)} \\ S_p(t) &= -\frac{\gamma C}{\mu} lnR_p + c_3 \quad where \quad c_3 \geq \frac{\gamma C}{\mu} lnR_p, \gamma = \frac{S_f - S_1}{C(t_f - t_1)} \\ P_p(t) &= -\frac{\alpha C}{\mu} lnR_p + c_4 \quad where \quad c_4 \geq \frac{\alpha C}{\mu} lnR_p, \alpha = \frac{P_f - P_1}{C(t_f - t_1)} \end{aligned}\right\} \qquad (27)$$

Mazibuko and Maharaj [13] collected HOTS data at eMnambithi TVET college in South Africa. Where they focused on students who were doing the N1 and N2 mathematics curriculum. The current study adopted the same data from the work of Mazibuko and Maharaj [1] and produced APPENDIX 2 by applying the fifteen outcomes explained above. Again, by applying Table 2 and APPENDIX 2 we produced Table 4.
Through the application of data Table 4 to the equations in (27) and estimation of the suitable integration constants, we produced the predicted compartments in Table 5 and visualized in Figure 3. It is visible from Table 5 that when the predicted compartments are rounded off to the nearest whole number, it is equal to the actual data compartment. Therefore, the RCUSP model is valid for the current data.

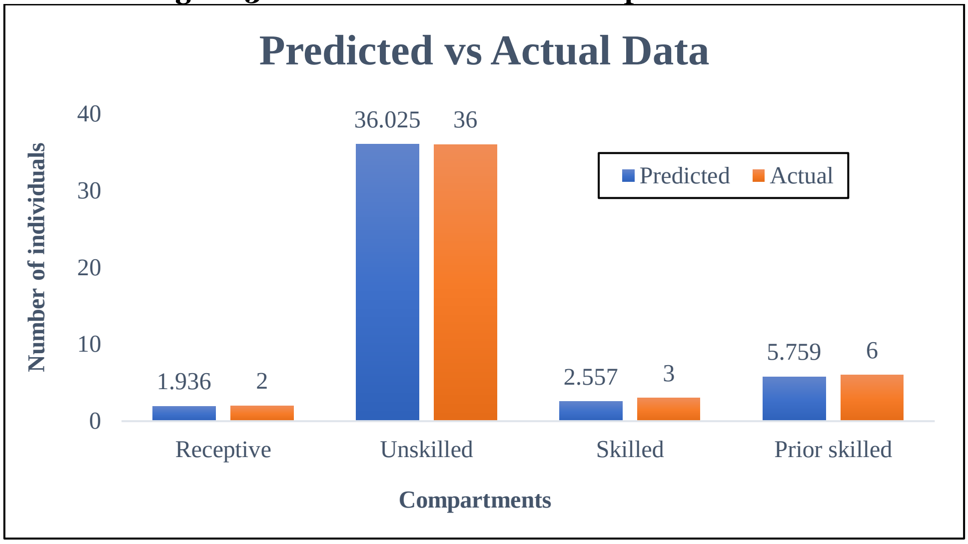
Table 4: RCUSP compartment values from the actual data in APPENDIX 2 [13].

Compartment Parameters	Actual Data Values
Initial time (in days)	$t_1 = 1$
Final time (in days)	$t_f = 180$
Initial individuals in the receptive	$R_1 = 47$
Final individuals in the receptive	$R_f = 2$
Initial unskilled individuals	$U_1 = 0$
Final unskilled individuals	$U_f = 36$
Initial prior skilled individuals	$P_1 = 0$
Final prior skilled individuals	$P_f = 6$
Initial skilled individuals	$S_1 = 0$
Final skilled individuals	$S_f = 3$
Individuals in the curriculum content	$C = 45$
Total number of individuals	$N = 47$

Table 5: Predicted versus actual RCUSP compartments.

Transition rates	Integration constants	Actual compartment at t_f	Predicted compartment at t_f
$\mu = 0.0176$	$c_1 = 46$	$R_f = 2$	$R_p = 1.936 \approx 2$
$\beta = 0.0045$	$c_2 = 44$	$U_f = 36$	$U_p = 36.025 \approx 36$
$\gamma = 0.0042$	$c_3 = 10$	$S_f = 3$	$S_p = 2.557 \approx 3$
$\alpha = 0.0007$	$c_4 = 7$	$P_f = 6$	$P_p = 5.759 \approx 6$

Figure 3: Predicted and actual compartment data



Model Application Test

As mentioned towards the end of sub-section 2.1, the HOTS was investigated by applying the extension of the RCUSP model called basic reproductive ratio. Substituting all necessary variables taken from *Table 4* into equations (26) and we get,

$$R_0 = 12.$$

This basic reproductive ratio relates to the case 1 ($R_0 > 1$) according to sub-section 2.1, which means the N1 to N2 mathematics curriculum might be incapable to equip students with HOTS.

RESULTS DISCUSSION

The current study produced a new curriculum evaluation model called RCUSP model. The compartments of the new model are relevant to the context of teaching and learning; since they do not present students as patients as was the case with the SVHIR model. Also, besides its alignment with the context of teaching and learning, the new model is a simplified version of the SVHIR model as it has less compartments to be predicted.

One of the primary objectives of the current study was to make the model accessible to all kinds of the readers. Hence, we included most of the mathematics steps during the model development for better understanding and application. In applying the model, it should be noted that there are three components that influences the outcome of equipping an individual with HOTS namely content delivery, student's readiness and curriculum. Therefore, to evaluate the curriculum the other two components should also be adequately evaluated. Conversely, in the current study's adopted data the content delivery and students' readiness has not been adequately evaluated. Hence, the results from the evaluation of the curriculum will be inconclusive when using the adopted data. However, for the purpose of testing the RCUSP model, we deliberately fixed the content delivery and students' readiness as adequate. In that regard, through the application of the reproductive ratio of the RCUSP model in sub-section 3.2, we found that the curriculum might be inadequate to equip students with HOTS. That conclusion is supported by APPENDIX 2, since out of forty-seven students only three were found to be skilled. On that statement, one can question the necessity of the reproductive ratio if it confirms what is already visible from the categorization of the compartments. Firstly, visually we can only see the performance of the curriculum, but as to how far is the curriculum performance from improving, it is visually impossible. That is where the reproductive ratio intervenes, given it is a numerical measure of the curriculum performance. Hence, with this parameter we get to know if there is a possibility of the curriculum performance to improve. In that regard, two cases of reproductive ratio were formulated to numerically base the conclusions. According to sub-section 2.1, case 1: the curriculum is incapable to equip students with HOTS, which means the curriculum performance will not improve and case 2: the curriculum is capable to equip students with HOTS, even if visually the curriculum performance seems to be inadequate but as time goes it will improve. Secondly, in the current study we do not consider visualization as enough evidence for our conclusions. Hence, the reproductive ratio gets more preference because it has enough evidence which is numerical.

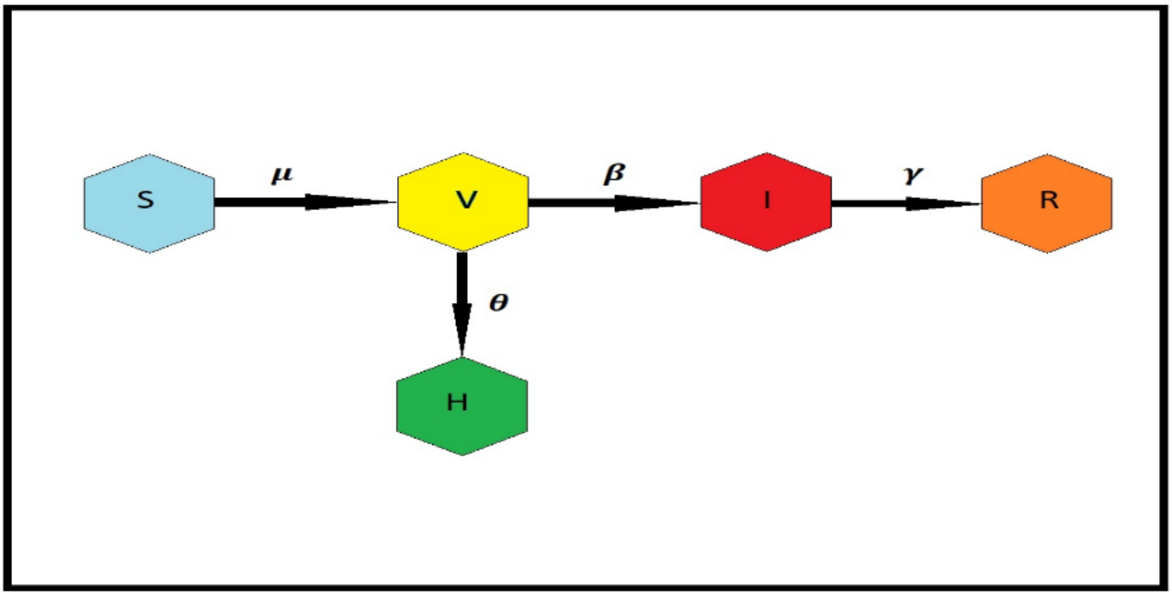
In addition, the application of the RCUSP model is only possible when the number of individuals in the curriculum content compartment (C) is known. The requiring of knowing C, do not discredit the effectiveness of the model. Our notion is that it is more beneficial to focus on predicting the future outcomes (Unskilled, Skilled and Prior skilled) given C, than to focus on predicting C and ignore the future outcomes. Hence, we decided to make C known to efficiently apply the RCUSP model. Further on, when C is known the new model can evaluate the effectiveness of any curriculum meant to equip individuals with any skill; given that it is the data collection instrument that determines the skill to be evaluated. However, to evaluate any skill a thorough study is required, that will focus on the structure of questions to be used for data collection. For HOTS, Maharaj and Wagh [14] a guide that could be used to formulate a data collection instrument.

CONCLUSIONS

This was a very broad study, which currently is at the early stages of development. The completion of this study will consist of adequate evaluation of the three components namely content delivery, students' readiness and curriculum content. Currently, the focus was still on perfecting the curriculum content evaluation. That was successfully achieved by the current study. A redevelopment of the HOTS evaluation model has been achieved, for the purpose of improving the weaknesses of the previously developed model. Those improvement were: the restructuring of the model compartments so that they don't categorize students who lacks HOTS as being sick; the inclusion of the model development details that were omitted in the previous model; the elaboration of the importance of the model and some parameters such reproductive ratio to enhance the understanding of the reader; the discovering of the newly developed RCUSP model that it is not limited only to HOTS but it is open to all curriculums and skills. In that regard, the current study holds a view that the curriculum content component is the only component out of the three that is ready for the evaluation of HOTS. Therefore, the next endeavor is to formulate an evaluation procedure for the two remaining components, then perform a proper HOTS evaluation where all the three components are considered.

APPENDIX 1: Summary of the Susceptible-vaccinated-healthy-infected-recovered (SVHIR) model

Figure A. Susceptible *S(t)*, vaccinated *V(t)*, healthy *H(t)*, infected *I(t)*, and recovered *R(t)* model (SVHIR Model).



The SVHIR model in Figure A is easily written using ordinary differential equations (ODEs) as follows:

$$\left.\begin{aligned} \frac{dS}{dt} &= -\mu S(t), && (a)\\ \frac{dV}{dt} &= \mu S(t) - \theta H(t) - \beta V(t), && (b)\\ \frac{dH}{dt} &= \theta V(t), && (c)\\ \frac{dI}{dt} &= \beta V(t) - \gamma I(t), && (d)\\ \frac{dR}{dt} &= \gamma I(t). && (e) \end{aligned}\right\} \qquad (i)$$

From integrating *(i)* and solving for the disease transmission rate (β) and Recovery rate (γ), a basic reproductive ratio of the SVHIR model is given as follows:

$$R_0 = \frac{\beta}{\gamma} \qquad (ii)$$

With the following two conditions or cases:
Case 1 ($R_0 > 1$) - This means the SVHIR model suggest that the curriculum has failed to equip students with HOTS.
Case 2 ($R_0 < 1$) - This means the SVHIR model suggest that the curriculum has equipped students with HOTS

APPENDIX 2: Pre- and Post-assessment of the student's HOTS scores

*Any negative percentage difference is set to be zero ($-x_i = 0$)

Student Order (i)	Part 2: HOTS (M_i)	Part 2: HOTS (M_i)	RCUSP Model Compartment
1	0	23	Unskilled
2	69	0	Unskilled
3	54	0	Unskilled
4	53	77	Prior skilled
5	53	15	Unskilled
6	46	0	Unskilled
7	38	46	Unskilled
8	54	0	Unskilled
9	38	0	Unskilled
10	38	0	Unskilled
11	38	0	Unskilled
12	46	0	Unskilled
13	38	0	Unskilled
14	0	0	Receptive
15	15	0	Unskilled
16	69	51	Prior skilled
17	23	0	Receptive
18	23	8	Unskilled
19	15	0	Unskilled
20	15	31	Unskilled
21	31	15	Unskilled
22	38	0	Unskilled
23	38	31	Unskilled
24	46	31	Unskilled
25	54	31	Unskilled
26	23	31	Unskilled
27	69	62	Prior skilled
28	15	23	Unskilled
29	84	100	Prior skilled
30	69	92	Prior skilled
31	15	31	Unskilled
32	54	77	Prior skilled
33	38	0	Unskilled
34	53	0	Unskilled
35	46	0	Unskilled
36	54	23	Unskilled
37	85	0	Unskilled
38	31	0	Unskilled
39	0	85	Skilled
40	0	100	Skilled
41	0	46	Unskilled
42	0	23	Unskilled
43	0	85	Skilled
44	0	38	Unskilled
45	0	38	Unskilled
46	0	46	Unskilled
47	0	46	Unskilled

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