The Simulation Based Learning (SBL): an Engineering Course on Salinity Forecasting of the Chao Phraya River Using Mathematical Modeling together with on-site Fieldwork

Khemisara Kulmart and Parichat Muensita
Ramkhamhaeng University, Thailand
Corresponding Author, E-mail: Khemisara.k@rumail.ru.ac.th

****

Abstract

The objectives of this study are to 1. To develop a simulation-based learning medium for students to be able to gain better and deeper knowledge and to actually pactice on skills by applying basic mathematics to real-life situations related to CVE4503, a water supply engineering and sanitary system course; 2.To familiarize students with problem solving processes skills through the newly acquired knowledge, Simulation Based Learning (SBL) using mathematical modeling together with on-site Fieldwork; and 3. To assess how efficient this particular learning medium could benefit the students and prompt them to accept the SBL learning medium.

Instead of targeting a specific population sampling group commonly used, this research intentionally opts for a targeted group of 28 third-year engineering undergraduate students from Ramkhamhaeng University who registered in the CVE4503 course.

The researcher used the following tools: mathematical models, exercises, assessment modules, and a form evaluating the acceptance of the innovative SBL to collect research data; to work on and study at the site of the Fieldwork.

The process of analyzing the data consisted of statistics percentage, mean, S.D., and (Process - E1/Product - E2: E1/E2). The result shown from using the SBL medium was effective as seen from the 93.00/84.07 score which was much higher than the standard 80/80.

The researcher had designed a post-test to verify the efficiency of the SBL medium anticipating the average score to be at 80%. However, the score turned out to be 95.36%.

The post-test assessment from students showed a high level of satisfaction with the SBL medium, 4.05/5.00. Therefore, the medium was demonstrated to be effective for active learning in future classes.

Keywords: Simulation Based Learning (SBL); Engineering Course; Salinity Forecasting; Mathematical Modelling

Introduction

The most crucial problem that we find in the academic society nowadays is the learners' lack of analytical and problem solving skills as well as the inability to apply classroom knowledge as a means to solve problems in real-life situations.

As the world entered the 21st century, educational circles around the world have been aware of the need to prepare learners for new learning experiences and environments including the rapidly evolving technological advancement.

* Received: August 3 2024; Revised: April 21 2024; Accepted: August 22 2024

Reorganizing for future higher education instruction medium in Thailand in the present era is vital to the development of learners skills and the enhancement of their potentials.Therefore the process of receiving and giving systematic instruction must be reformed and adapted to suit the learners' learning process, (office of the Education Council, 2561), especially in the field of Science and Mathematical.

As mathematics instructors, we place great importance on designing instruction courses that go beyond just learning theories and solving hypothetical problems in the classroom. We see the need to create a new innovative learning medium aiming for the goal to ensure that students can successfully apply their mathematical knowledge to successfully solve real-life problems, resulting in tangible benefits. Students who pass this new teaching approach course gaining enough knowledge and hands-on skills shall be able to see that this new innovative learning medium can serve as a model for creating future new innovations and they themselves can actually become future innovators.

Simulation-based learning (SBL) has become an increasingly popular approach in education and training, particularly in fields where real-lift experience can be difficult or risky to obtain. By creating virtual environments that mimic real-life situations, simulation-based learning allows learners to practice and develop their skills in a safe and controlled setting, Somchit Sinthuchai and Kanyarat Ubonwan (2017). This approach can be used in a variety of settings, from medical and military training to business and leadership development, ThitNa Khaemmani, (2023). In this era of rapid technological advancement, simulation-based learning is poised to become an even more integral part of education and training, offering learners the opportunity to gain hands-on experience and develop the skills they need to succeed in their chosen fields.

The authors firmly believe that learning through virtual simulation using mathematical models in combination with on-site freld trip, which are the basis of curriculum analysis, learning objectives, and previous research, can help learners to create connections between the understanding of scientific concepts and the situations that occur in real life. It can also help learners to solve real-world problems using mathematical modeling. Currently,the skill of mathematical analytical thinking, particularly the use of mathematical modeling, involves using mathematical functions and symbols to represent elements in real-life systems or everyday life situations. This process requires the application of mathematical knowledge, principles, and methods such as equations, inequalities, functions, variables, and graphs, to solve problems. The solutions derived from the mathematical modeling are then adjusted to fit real-life problems. Students must convert real-life problems or situations into mathematical problem situations.To achieve this, it is essential to have instructional materials that help students clearly visualize the situations being studied and easily understand the concepts in relatable contexts, (Supapen Panawatphisut et al., 2019), Kolb's experiential learning theory (1984). This will lead to meaningful understanding and awareness of various situations that occur on Earth, Suphaphen Panawatphisut et al., (2019). This may even be more effective when simulations are employed together with learning-by-doing sessions in the classroom and in on-site Fieldwork settings.

Simulation Based Learning: SBL is relatively new to Thailand's academic society which focuses on Active Learning: AL where teachers perform as Facilitators guiding learners while applying SBL to an on-site Fieldwork. Such learning process opens up the opportunities for learners to be equipped with proper tools to actually practice when facing problems in real life situations. This shall encourage learning ability, promote vocational competency, help keep up with evolving technological advancement so that learners' confidence, problem solving skills, remarkable expressiveness and decision-making shall eventually follow, (Thitna Khaemmani, 2023).

This is the reason why the researcher designs " various types and tools to be used in the process of systematic instruction" compatible to the specified context of the classroom as well as a "diverse active-learning activities" to elevate learners' potential and competency.

The above mentioned process of receiving and giving systematic instruction design stresses hands-on practice in close contact with current situations and learners ability to solve problems on their own (Thitna Khaemmani, 2023).

In this study, an SBL on-site Fieldwork Course was developed to be taught to bachelor's degree engineering students. The course is a water supply engineering and sanitary system course. In the course, students will learned about mathematical models and used a mathematical modeling to simulate and predict salinity level in the Chao Phraya River, Thailand.

Research Objectives

The objectives of this study were to:

1.To develop a simulation-based learning medium for students to be able to gain better and deeper knowledge and to actually practice on skills by applying basic mathematics to real-life situations related to CVE4503, a water supply engineering and sanitary system course.

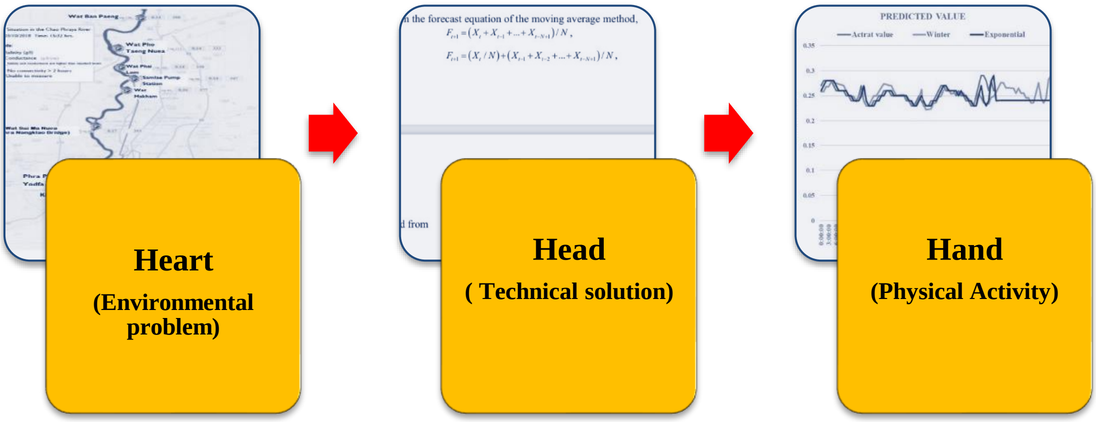
2.To familiarize students with problem solving processes skills through the newly acquired knowledge, Simulation Based Learning (SBL) using mathematical modeling together with on site Fieldwork.

3.To assess how efficient this particular learning medium could benefit the students and prompt them to accept the SBL learning medium.

Research Conceptual Background

In the CVE4503 classroom, the instructor examines the curriculum, analyzes the content, and sets objectives, learning goals, components, and principles of teaching by virtual simulation using mathematical modeling. The instructor uses teaching methods in the context of active learning. The goal is Competency (Learning Outcome), which is for the learners to be able to successfully apply the knowledge, skills, attitudes, and acquired characteristics when facing real situations, problems, obstacles, and challenges.

The thinking behind this study is to bring applied mathematics from the mathematics research literature to the students in order to get them familiar with the applications of mathematical modelling. The sequence of learning is, first, to get the students to become familiar with several mathematical models in the literature. Then, let them investigate how to apply one of those models to real-world situations, as shown in Figures 1.



Figures, 1 Active learning: Heart, Head, Hand (3H): Represents the Conceptual Background of this research in that:

- **Heart** is the heart of the Problem. In this case, the currently existing problem in our environment is the salinity level in the Chao Phraya River. This issue is one of the subjects explored in the department of civil engineering.
- **Head** means using the innovative Simulation Based Learning (SBL) using mathematical modeling together with on site Fieldwork to collect research data; to study and work on at the site of the problem. In this case, the site is at Sam Lae Pump Station.
- **Hand** refers to the implementation of Technical skills used resulting in tangible outcomes.

Simulation-Based Learning Methodology

In this section, we describe the steps in the method of our simulation-based learning.
Step 1: Pick simulation site
After the instructor and the students have decided on a topic relevant to water engineering, the instructor took the class to the site. In this case, the Chao Phraya River Sam Lae Pump Station as seen in Figure 2 and Figure 3 showing the water control equipment and water quality assessment equipment.

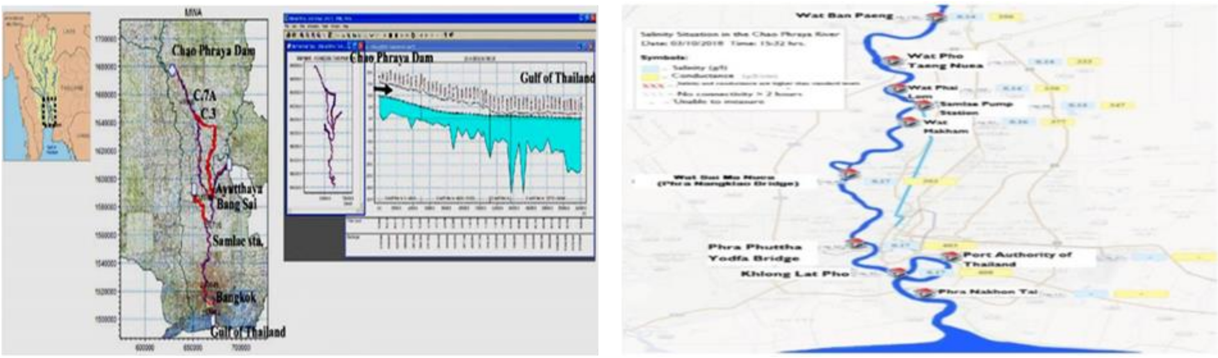
Figures, 2 Water control equipment and water quality assessment equipment

Figures, 3 Chao Phraya River and pumping stations: https://www.istockphoto.com/th

Step 2: Identify the exisiting salinity level in Chao Phraya River:

The student spent 4 hours attending the texture and explored the whole Sam Lae Pump Station complex.They learned that the station must monitor the salinity level of the water reading from 10 salinity meters installed along the Chao Phraya River plus a conventional means gauging from the reaction of a school Asian Bass (Pla Krapong) that the station staff raised in tank.

When sea water reached the station, the fish became restless. The students were also shown graphical data as seen in Figure 4



Figures, 4 Lower Chao Phraya River and levels of seawater intrusion along the river (Ruang, 1999)

Step 3: Salinity level analysis using mathematical modelling

The salinity level in Chao Phraya River was simulated by mathematical modelling. The students learned how to use mathematical modelling and the simulation outcomes. The students could anticipate the actual outcome at a specific time and place with a clear understanding of the modelling. The idea of this step was based on Kolb's experiential learning theory 1984. Figure 3 shows the lower Chao Phraya River and levels of seawater intrusion along the river (Ruang, 1999).

In detail, the students learned the following mathematical modeling (Edward, 1997).

The starting lecture was as follows. In forecasting the data $t+1$, observations of time $t, t-1, t-2, t-3, ..., t-n$ collected in large numbers can be taken advantage of. Weather forecast system, meteorological department warning, and water resource warning will know the time period to forecast in advance (Khemisara Kulmart & Chamnan Charoenroongruang, 2024).

From the forecast equation of the moving average method, $F_{t+1} = \left(X_t + X_{t-1} + ... + X_{t-N+1}\right)/N$,

$$F_{t+1} = \left(X_t / N\right) + \left(X_{t-1} + X_{t-2} + ... + X_{t-N+1}\right)/N ,$$

and from $$F_t = \left(X_{t-1} + X_{t-2} + ... + X_{t-N+1} + X_{t-N}\right)/N ,$$

$$F_{t+1} = \left(X / N\right) + \left(F_t - X_{t-N}\right)/N , \quad (1)$$

but since X_{t-N} cannot be determined directly, time series datasets are stationary, and there was no pattern in the data, so X_{t-N} is estimated from F_{t+1}. From equation (1),

$$F_{t+1} = \left(X / N\right) + F_t - \left(F_t / N\right)$$

$$F_{t+1} = \left(1/N\right) X_t + \left(1 - \left(1/N\right)\right) F_t$$

Set the weighted value $1/N$ for the most current data value and weight $\left(1-\left(1/N\right)\right)$ for the most current forecast value, given $\alpha = 1/N$ and $0 < \alpha < 1$ The forecasting equation is

$$F_{t+1} = \alpha X_t + \left(1-\alpha\right) F_t \quad (2)$$

This equation is the basic model used for calculating future salinity level. Equation (2) can be distributed in the form of historical data values, which are

$$F_{t+1} = \alpha X_t + \left(1-\alpha\right)\left[\alpha X_{t-1} + \left(1-\alpha\right) F_{t-1}\right],$$

$$F_{t+1} = \alpha X_t + \alpha\left(1-\alpha\right) X_{t-1} + \left(1-\alpha\right)^2 F_{t-1},$$

$$F_{t+1} = \alpha X_t + \alpha\left(1-\alpha\right) X_{t-1} + \left(1-\alpha\right)^2 \left[\alpha X_{t-2} + \left(1-\alpha\right) F_{t-2}\right],$$

$$F_{t+1} = \alpha X_t + \alpha(1-\alpha) X_{t-1} + \alpha\left(1-\alpha\right)^2 X_{t-2} + \left(1-\alpha\right)^3 X_{t-3} + ... \quad (3)$$

Equation (2) can also be distributed as,

$$F_{t+1} = \alpha X_t + F_t - \alpha F_t = F_t + \alpha\left[X_t - F_t\right], \quad (4)$$

and $e_t = X_t - F_t$ is the discrepancy in the agenda t (residual),

$$F_{t+1} = F_t + \alpha e_t \ . \tag{5}$$

Smoothing equation: $S_t = \alpha\left[X_t / I_{t-L}\right] + (1-\alpha)(S_{t-1} + b_{t-1})$,

Trend determination equation: $b_t = \gamma(S_t - S_{t-1}) + (1-\gamma)b_{t-1}$,

Seasonal equation: $I_t = \beta(X_t - S_t) + (1-\beta)I_{t-L}$.

The prediction equation is

$$F_{t+m} = (S_t + b_t m) I_{t-L+m}\ , \tag{6}$$

where $0 < \alpha < 1$, $0 < \beta < 1$, and $0 < \gamma < 1$.

In the equations above, L is the length of the season

I It is an adjusted season factor (seasonal adjustment factor)

S_t = smoothing value at t,

b_t = trend value at t,

I_t = seasonal estimate at t,

α = smoothing constant, $0 < \alpha < 1$,

γ = slope constant, $0 < \beta < 1$,

β = seasonal constant, $0 < \gamma < 1$,

X_t = observed value at t,

m = future prediction time period, $m = 1, 2, 3, ...$

F_{t+m} = predicted value at $t + m$.

Prediction error is the difference between actual measured value and predicted value, expressed mathematically as

$$e_t = \left|X_t - F_t\right|, \tag{7}$$

where F_t = predicted forecast salinity level at t

X_t = actual measured salinity level at t

e_t = error at t

In this study, Mean Square Error (MSE) is the selected error measure,

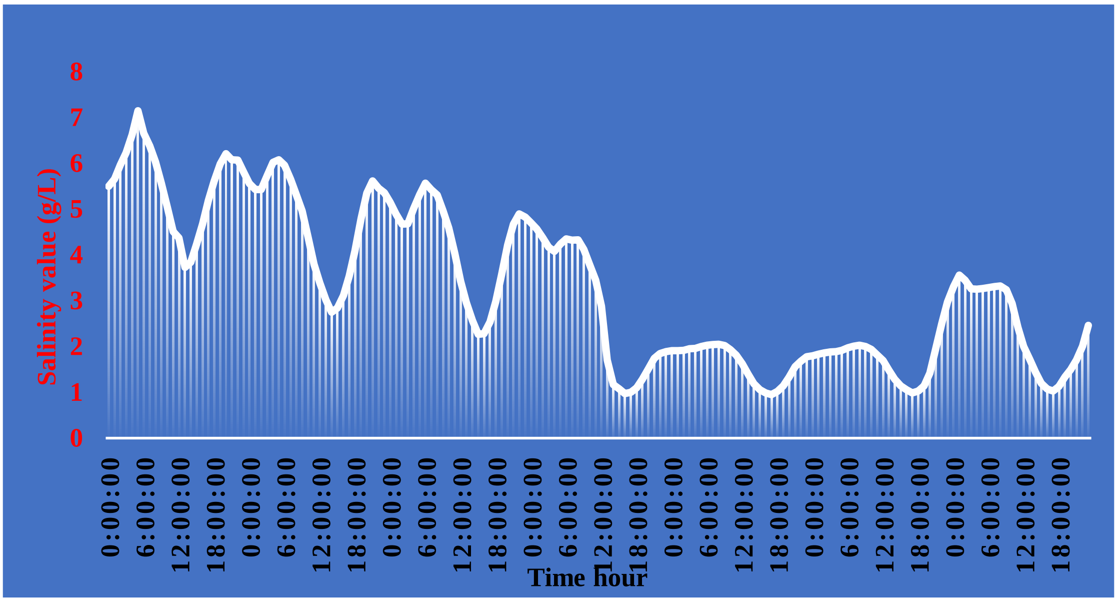
$$MSE = \sum_{t=1}^{n} \frac{(actual - forecast)^2}{n} = \frac{\sum_{t=1}^{n} (e_t)^2}{n}. \quad (8)$$

Step 4: Compare mathematical modeling analysis outcomes with data from Sam Lae Pump Station

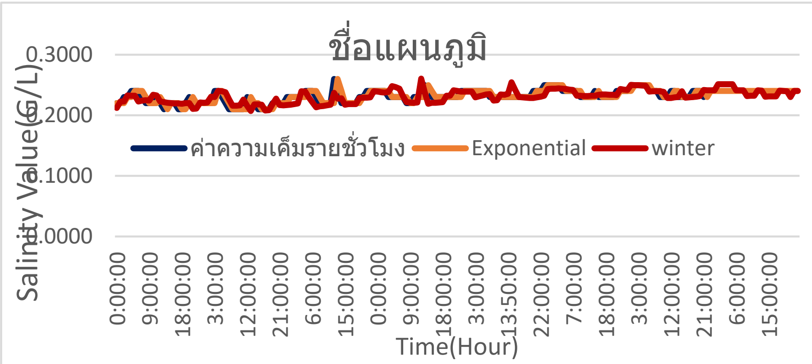
Records of actual salinity level during 01/07/2020 to 03/06/2022 were used in the simulation. Given a future time period in the records, the model could output a predicted salinity level during that period, so the students could check whether their predictions matched the actual levels recorded. We could see that the outcome of the mathematical modelling is not so far off from the outcome found at Sam Lae Pump Station.

The students also performed field work with real equipment to get a feel of the real situation. Their learning outcomes and their satisfaction with the course were evaluated.

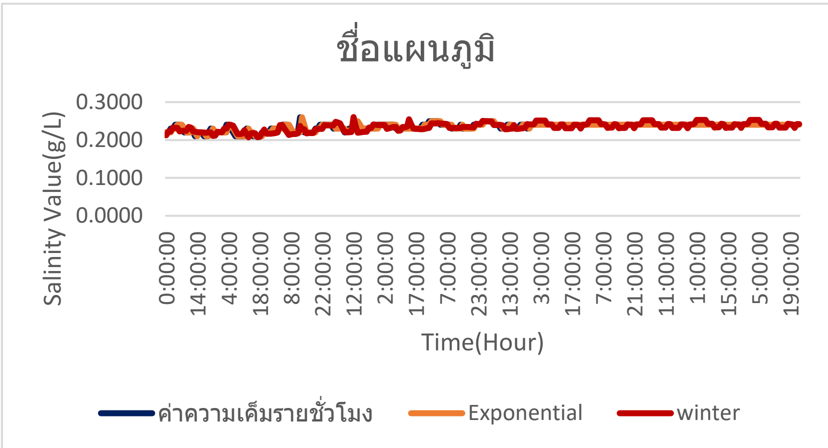
Figures, 5-10 shows summaries of simulation outcomes. The students analyzed and discussed the simulation results with reference to the actual results from the Pump Station.



Figures, 5 Graph showing hourly salinity at Khlong Lat Pho Water Quality Monitoring Station (One of the 10 stalled salinity meter site) since 1 July 2020 – 30 June 2022 (168 hours)

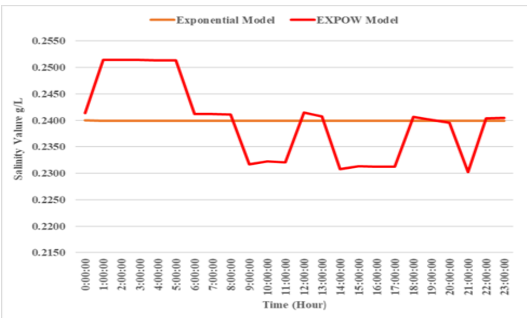


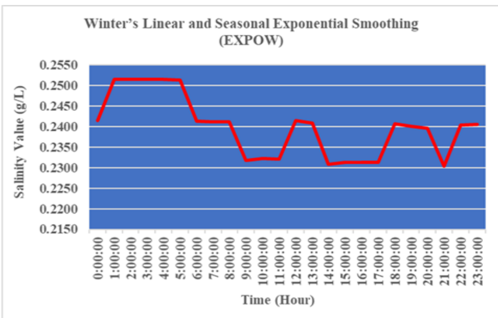
Figures, 5 Graph comparing Actual value (g/l) and Prediced value (g/l) by Exponential Model and Winter Model and hourly salinity forecast of Kholong Lat Pho Water QualityMonitorring Slation 24 hours inf advance salinity forecast (24-30/6/2022) and Predicted value 01/07/2022 (24 Hours))



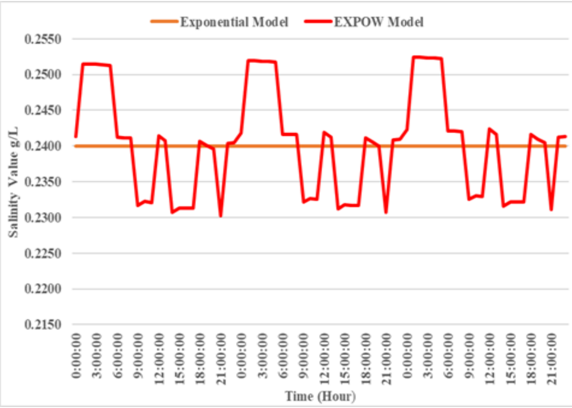
Figures, 6 Graph showing Compare Actual value (g/l) and Predicted value (g/l) by Exponential Model and Winter Model and hourly salinity forecast of Khlong Lat Pho Water Quality Monitoring Station 72 hours in advance salinity forecast (24-30/06/2022) amd Predicted value 1-3/07/2022 (72 Hours.)

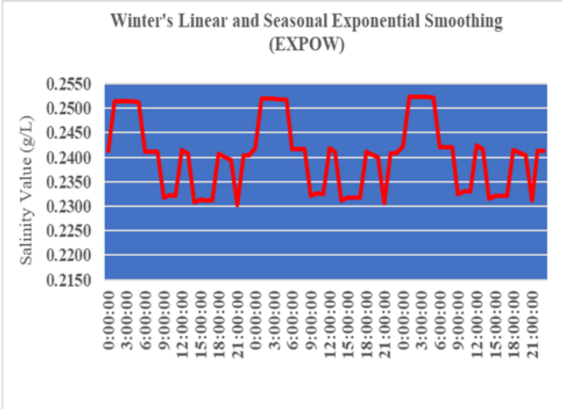
To show our final forecast clearly, Figures 8, Figures 9 and Figures 10 show the forecast made by EXPOW, the technique of choice.



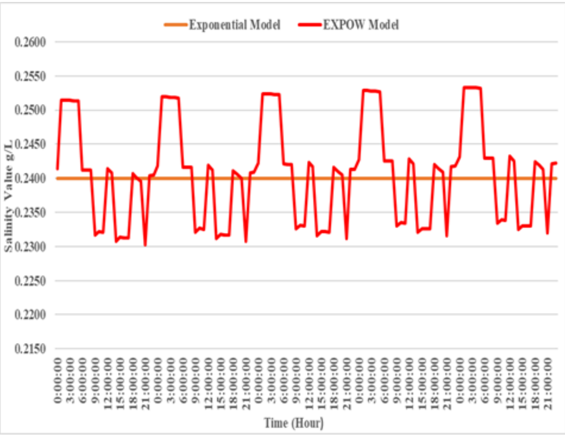


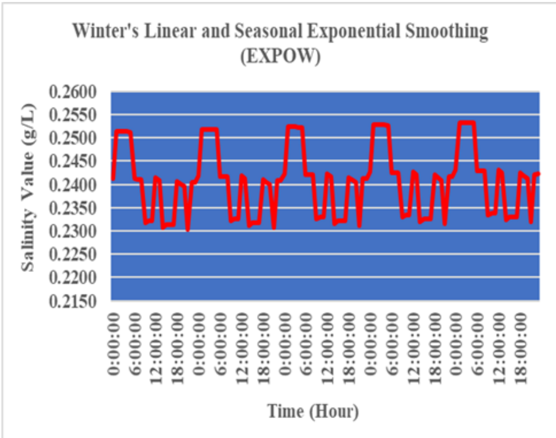
Figures , 8 In advance salinity forecast by Winter Model (24 Hr.) 01/07/2022





Figures, 9 In advance salinity forecast by Winter Model (72 hr.) 01-03/07/2022

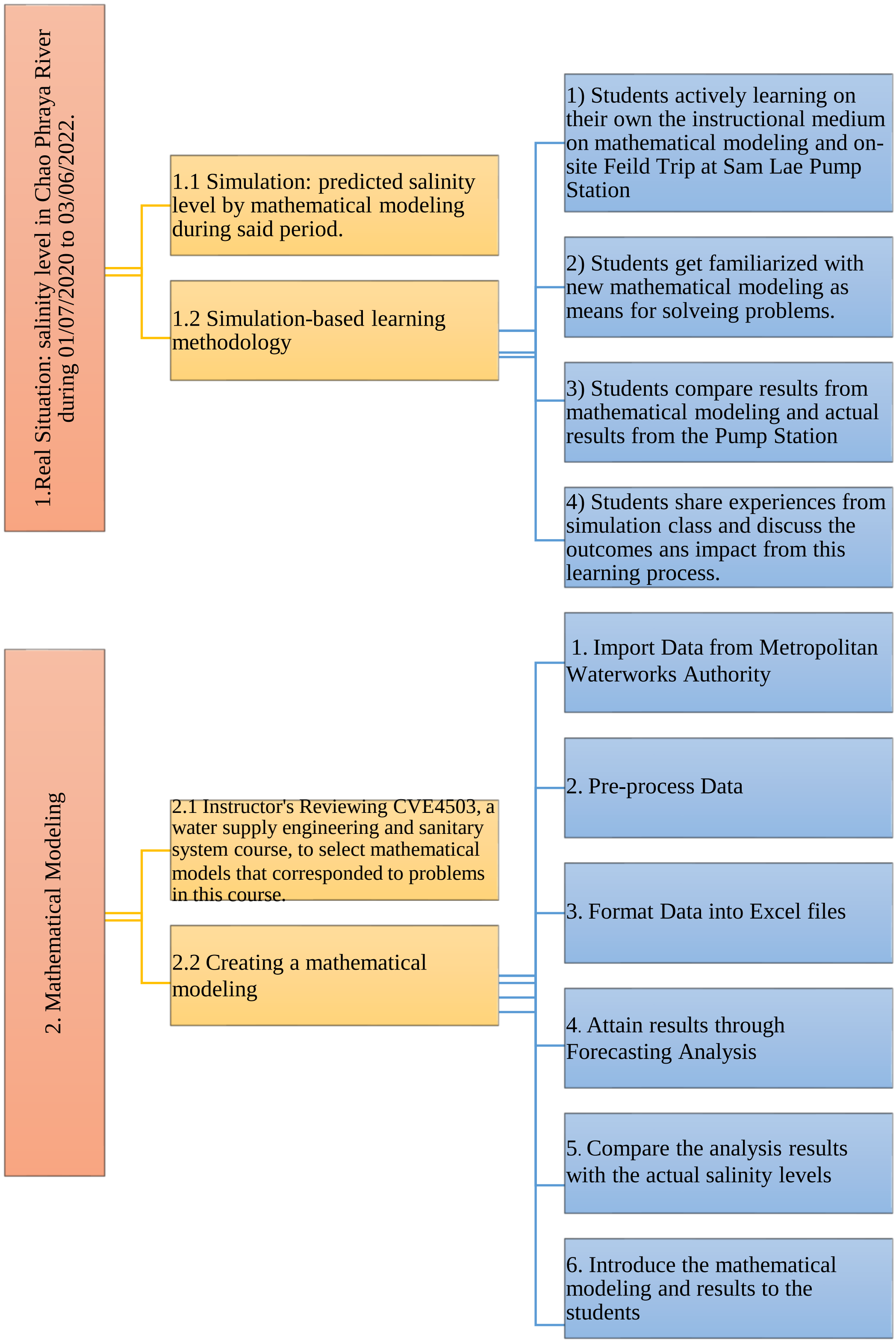




Figures, 10 In advance salinity forecast by Winter Model (120 hr.) 01-05/07/2022

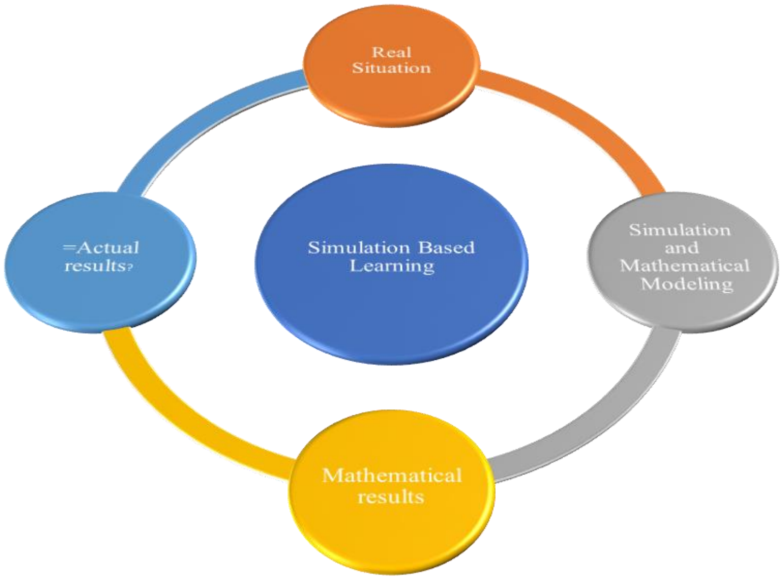
Two points were discussed in this step: comparison of techniques and suitable time for pumping the water at the pumping station. Regarding the two techniques, the single exponential smoothing model provided the lowest mean squared error but failed to make accurate forecast—the predicted value always converged to a constant. On the other hand, the EXPOW model was able to make reliable predictions. Regarding suitable pumping time, to produce good quality tap water, the Metropolitan Waterworks Authority Pumping should arrange pumping during the period of minimum salinity because pumping water during this time will make the production of tap water cost less to produce than during other times when salinity level was higher. According to the 24-hour forecast results, the most suitable water pumping time for agriculture or tap water production was between 7:00 p.m. and 8:00 p.m., when the water salinity level was the lowest at 0.2355 g/l. and during 2:00 p.m. – 4:00 p.m., which had a salinity value of 0.2358 – 0.2361 g/l. The next suitable time was between 12:00 - 14:00, which had the salinity of water at 0.2455 - 0.2458 g/L during the period from 21:00 to 23:00.

The overall method of the study is summarized and shown in the diagram in flowchart 1 applied from the idea of this step was based on Kolb's experiential learning theory 1988.



Flowchart, 1 Overall florwchat of methodology of the study

The simulation-based learning happened in cycles min map simple, as shown in Figure 11 below. The students practiced and performed higher order thinking according to Gibbs Reflective Cycle 1988.



Figures, 11 Simulation-Based Learning Mathematical Modeling:
SBLM cycle min map simple

Research Scope

Target group for research

Instead of targeting a specific population sampling group commonly used, this research intentionally opted for a targeted group of 28 third year engineering undergraduate students from Ramkhamhaeng University who registered in CVE4503 course and were willing to participate in the research. This target group were undergraduate students 1st academic year 2022 (section 3) from the department of waterworks engineering, sanitary systems. The reason being, the researcher aimed for the result of using the Simulation Based Learning (SBL): an engineering Course Salinity Forecasting by Mathematical Modeling to help enhance the development of students' potential. The students who should be able to gain this specific target group shared most of the characteristics compatible with this designed research.

Instrument

The quality of every research tool comprises the mathematical models, the exercises, and the pre and post-test which must be examined and approved by a panel of three experts. The evaluated results, in terms of Index of item Objective Congruence (IOC), on the subject content, logical sequence, language, exercise, and satisfaction level towards the course were all in the range of 0.67-1.00. The levels of the quality of test papers were tabulated in Table 1.

Table, 1 Quality of test papers

Reliability statistics	**Quality of test papers (Items)**			
	1	**2**	**3**	**4**
Scannell and Tracy, 1975: 223 (Difficulty Index), (p) $IDiff = (0.20 - 0.80)$	0.61	0.73	0.65	0.53
Scannell and Tracy, 1975: 228 (Discrimination Index), (r) $IDisc > 0.30$	0.30	0.54	0.62	0.58
Reliability Statistics (N of Items = 4)	Cronbach's Alpha coefficient: α			
	.702			

Results

1.The process of analyzing the data consisted of statistics percentage, mean, S.D., and (Process - E1/Product - E2: E1/E2). The result shown from using the SBL medium was effective as seen from the 93.00/84.07 score whith was much higher than the standard 80/80. As seen at table 2.

Table, 2 The efficiency of this SBL.

Tool	**N**	**Percentages**
Process (E_1)	28	93.00
Product (E_2)	28	84.07

2.The researcher had designed a post – test to verify the efficiency of the SBL medium anticipating the average score to be at 80%. However, the score turned out to be 95.36%. As seen at table 3.

Table, 3 post-test score on field work

Tool	**N**	**Mean**	*S.D.*	**Percentages**
Pre-Experiment: One-group post-test only design	28	95.36	6.37	95.36

3.And the post – test assessment from students showed a high level of satisfaction with the SBL medium, 4.05/5.00. Therefore, the medium was demonstrated to be effective for active learning in future classes. As seen at table 4.

Table, 4 Students' satisfaction towards simulation-based learning

Statement	**Mean**	*S.D.*	**Interpretation**
1.Perceive Usefulness	4.03	6.25	fair
2.Perceived	3.98	8.07	fair
3.1 Feedback	4.19	7.77	fair
3.2 Interaction and participation	4.51*	6.38	Excellent
3.3 Measurement and evaluation	3.97	6.94	fair
4.Intention to use	4.03	6.63	fair
Average	4.05	7.00	fair

Discussion

1. The results regarding assessing the effectiveness of the Simulation-Based Learning (SBL) approach, which combines mathematical modeling with hands-on field practice for reviewing knowledge and enhancing the ability to connect fundamental mathematical concepts to problem-solving in various related situations for the CVE4503 course on Water Supply and Sanitation Engineering (Section 3), showed an efficiency score of 93.00/84.07, which is higher than the established criteria of 80/80.

This outcome is attributed to the researcher's careful planning and preparation of the instructional model in advance, comprehensive literature review, detailed explanation of rules and procedures to the students, and active involvement in teaching where the developed model was analyzed, summarized, and presented in an international forum. Additionally, the researcher has extensive experience in developing mathematical models based on real-life problems as well as analyzing them to derive mathematical solutions. The SBL approach involved using mathematical simulations along with actual field practice, allowing students to engage actively, analyze data independently using the developed model, work with real equipment, and participate in discussions and knowledge exchange with water supply experts. The results obtained from the simulations were compared with real-life data, aligning with the findings of Schukajlow and Schukajlow (2012). Who stated that mathematics is closely related to real-life and can be categorized into three types of mathematical problems: intra-mathematical problems, word problems, and modeling problems. This also corresponds with the research by Supapen Panawattanapisut et al., (2019), which emphasizes the importance of instructional materials that provide a clear visualization of the situations involved, making it easier for students to understand real-life problems. Furthermore, it aligns with the ideas of Tisana Khammani (2023), who noted that teaching through simulations is a method designed to help learners understand the realities represented by the simulated situations, allowing them to learn through their active participation in those situations.

2. The results regarding enhancing the capabilities of targeted students in the CVE4503 course on water supply and sanitary Engineering (Section 3) demonstrated that their ability to develop potential, skills, and understanding in becoming familiar with problem-solving processes, leading to outcomes exceeding the set criteria by more than 80%.

This success is attributed to the Simulation-Based Learning (SBL) approach, which encouraged students to become more engaged in their learning, seek answers independently, and emphasized hands-on practice and knowledge creation through active participation. This aligns with the teaching method described by Paitoon Sinlarat (2023), who explained that shifting from teacher-centered to student-centered instruction stimulates greater enthusiasm for learning. It also corresponds with the research findings of Somchit Sinthuchai and Kanyarat Ubonwan (2017), as well as those from Boromarajonani College of Nursing (2019), which integrate the development of 21st-century skills (Sansanee Nentien, 2017). Active learning activities, which emphasize practice and knowledge creation through hands-on experiences during instruction, were shown to be effective. This is consistent with the research by Wanna Khumso (2012), which studied the development of multimedia lessons using simulation situations on materials used and their properties while teaching 5th-grade students, achieving a score of 80.22/80.87, higher than the set criteria of 75/75. The learning outcomes from the multimedia simulation lessons were significantly higher after instruction compared to before, at a statistical significance level of .01. This approach also aligns with Jeffries' Simulation Framework (2008), which emphasizes that simulation-based teaching encourages students to assess and act according to the situation and evaluate the outcomes of their actions.

3. The results regarding student acceptance towards the Simulation-Based Learning (SBL) approach, which combines mathematical modeling with hands-on fieldwork, revealed an overall average score of 4.05/5.00. The qualitative assessment indicated a high level of satisfaction.

This positive outcome is attributed to students having the opportunity to learn and develop problem-solving skills in real-life situations relevant to engineering studies. The shift from traditional classroom lectures to a format that includes collaborative learning with specialized experts in water production and fieldwork at the Sam Lae Pump Station allowed students to analyze data and use real equipment. The evaluation forms completed by the students show that they highly accepted this teaching method. When reviewing the feedback, it is clear that all aspects of the evaluation were rated at a high level. Allowing students to express their opinions on the simulated situations using mathematical modeling enabled them to gain significant real-life experience, particularly in improving their analytical thinking and decision-making speed. This aligns with Rogers' (2003) Innovation Decision Process Theory, which explains that innovation promoters often use various methods to encourage individuals to adopt innovations, such as offering assistance, providing guidance on how to use the innovation, hands-on practice, demonstrations, role models, and situations simulations. Additionally, positive impacts on students were observed, including their excitement, engagement, happiness, and enjoyment in learning.

Conclusion

At the end of this research, we found out that learners who enrolled in the SBL – Fiele Trip Course stressing hands-on practice in close contact with current situations can really be motivated to enjoy acquiring knowledge through this innovative instruction medium and improve their ability to solve problems on their own.

Therefore, the result of this research clearly indicated the efficiency of applying The Simulation Based Learning (SBL): an Engineering Course on Salinity Forecasting of the Chao Phraya River by using Mathematical Modeling together with on site Fieldwork to CVE4503 Course

The course was well-received and effective, accomplishing a student acceptance level of 4.05 out of 5 and an E1/E2 of 93.00/84.07. The students were actively learning the subject and enjoyed interactions with their classmates. In the future, the author will apply simulation-based learning to other subjects and fields of study.

Suggestions

Suggestions for Applying the Research Findings

1. SBL (Simulation-Based Learning) can be applied across various academic disciplines and professional fields. Users can adapt it to fit the specific content and practical context of each field. For example in estimating PM 2.5 levels.

2. Teachers can use SBL as a tool to facilitate hands-on learning, allowing students to practice skills relevant to solving real-life problems.

3. The researcher hopes that SBL will become one of the approaches for creating new teaching materials and instructional methods, aimed at enhancing and improving student learning outcomes.

Suggestions for Future Research

1. Researchers should thoroughly study the relevant data, problems, and case studies related to the subject matter before creating the desired mathematical simulations.

2. Content and tools from fields such as physics, chemistry, and computational sciences can be integrated with mathematics to design and develop structures, machinery, production processes, or even create devices that replace human tasks for maximum benefit, such as applying AI.

3. Interesting research topics include water quality assessment, water pollution forecasting, water resource management, pollution control, the use of biohazard warning systems, and the development of mathematical equations in conjunction with AI, among others.

Data Availability

Data availability statement: Access to raw data is convenient. The following files are archived at Google Drive: a PDF file containing a list of links to various papers used in the SBL course; two Excel files, one containing raw data of hourly salinity levels of Chao Phraya River from January 6, 2020 to February 7, 2022, and the other one containing selected raw data for student practice. The link to these files is [13]

https://drive.google.com/drive/folders/1D-HTjmgl9fnnYSsGJVbJKxLy2NyhbxdM?usp=sharing.

Supplementary Materials: 1. *Data salinity for* 2020-22. 2. *Data salinity for* 2022.

Conflicts of Interest

The authors declare that there are no conflicts of interest with any party regarding the publication of this paper.

Funding

This study was not funded by any grant. It was conducted under the author's responsibility to their employer, Ramkhamhaeng University, and performed as part of the employment of the authors. Ramkhamhaeng University was not involved in the manuscript writing, editing, approval, or decision to publish this paper in any way.

Acknowledgments

The data for this research were supported by the Metropolitan Waterworks Authority, Water Resources and Environment Department. The authors greatly appreciate valuable comments received from the referees at the Faculty of Education and Faculty of Engineering, Ramkhamhaeng University, Thailand. Especially, we are grateful to the staff at Samlae Pump Station for helping us throughout the project.

References

Arseven, A. (2015). Mathematical Modelling Approach in Mathematics Education. *Universal Journal of Educational Research*, 3 (12), 973-980.

Bakoush, M. (2022). Evaluating the role of simulation-based experiential learning in improving satisfaction of finance students. *The International Journal of Management Education,* 20 (2022).

Brahmawong, C. (2013). Developmental Testing of Media and Instructional Package. *Silpakorn Educational Research*, 5 (1), 7-20.

Cai, J., Cirillo, M., Pelesko, J. A., Ferri, R. B., Borba, M., Geiger, V., Stillman, G., English, L. D., Wake, G., Kaiser, G., & Kwon, O. N. (2014). Mathematical Modeling in School Education: Mathematical, Cognitive, Curricular, Instruction, And Teacher Education Perspective. *38th International Conference of Psychology of Mathematics Education.*

Erbas, A. K., Kertil, M. Cetinkata, B., Cakiroglu, E., Alacaci, C., & Bas, S. (2014). Mathematical Modeling in Mathematics Education Basic Concepts and Approaches. *Education Sciences Theory & Practics,* 14 (4), 1621-1627.

Fernandez, N. J., & IPaul, I. (2021). Effect of Computer-Assisted Instruction in Simulation Mode for Learning Mathematics on students at Secondary school level International. *Journal of Mechanical Engineering*, 6 (Special Issue), 262-269.

Hallinger, P., & Wang, R. (2020). Analyzing the intellectual structure of research on simulation-based learning in management education, 1960–2019: A bibliometric review. *The International Journal of Management Education*, 18 (3), 1-13.

Khumso, W. (2012). *The development of simulated mutimedia lesson on materail and properties of materail to enhance science process observation and experimental skills of primary students grade 5, Anubanphotharam School.* [Master's thesis, Silpakorn Universit]. http://www.thapra.lib.su.ac.th/thesis.

Kutmart, K., & Charoenroongruang, C. (2023). Mathematical forecasting simulation of salinity intrusion in Chao Phraya River". *Journal of Information and Optimization Sciences. ISSN 0252-2667 (Print), ISSN 2169-0103 (Online)*,45 (2024), 181–198.

Lee, B., Lee, M., & Fredendall, L. (2022). Response to relative performance feedback in simulation games. *The International Journal of Management Education 20 (2022).*

Nenthian, S. (2017). Mathematics Learning with Real-World Problems Based on Mathematical Modeling. *Warasan Kharusat*, 45 (2), 238-253.

Nentien, s. (2017). Mathematics Learning with Real-World Problems Basedon Mathematical Modeling. *Journal of Education*, 45 (2), 238-253.

Office of the National Education Commission. (2002). *National Education Act B.E. 2542 (Additional 2) B.E. 2545*. Bangkok.

Paitoon Sinlarat. (2023). *27 teaching methods to develop learners' potential*. National Library of Thailand Cataloging in Publication Data.

Panawatthanapisuit, s. (2019). The Development of an Instructional Skill Using Simulation Based LearningRajavadee . *Journal, Boromarajonani College of Nursing, Surin*, 9 (2), 55-70.

Ruang, S. (1999). *Statistical Forecasting Methods*. Department static and computer Faculty of Science Ramkhamhaeng University.

Schukajlow, S. (2012). *Mathematises Madeliene.* WAXMANN.

Somchit, S., & Ubonwan, K. (2017). Fidelity Simulation Based Learning: Implementation to Learning and Teaching Management. *Journal of The Royal Thai Army Nurses*, 18 (1), 29-38.

Sukamonson, S. (2004). Kan Wikhro Kho Thotsop Baep Attanai Rai Kho. *Pasaa Paritat Journal*, 21, 44-55.

ThitNa Khaemmani. (2023). *The Science of Teaching.* Chulalongkorn University Press.

Zavalani, O., & Kacani, J. (2012). Mathematical Modelling and Simulation in Engineering Education. *Authorized licensed use limited to: Ramkhamhaeng University provided by UniNet, IEEE 978-4673-4/12.*