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Learning Circulation & Hemodynamics using an Interactive Simulation Package through a Graphic User Interface

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Abstract

Circulation system & hemodynamics is one of the advanced topics in an undergraduate mechanical engineering course on bioengineering applications. It studies the dynamics of blood flow which is directly related to fluid mechanics. The interdisciplinary nature of the subject poses multiple challenges in teaching and learning. Often times, students are unfamiliar with the medical context of the human circulatory system and the pathological/activity states. They have little or no experience working with the pulsatile flow (heartbeat), soft pipes (blood vessels), and one-way valves (heart valves).

To address these challenges, an interactive simulation model supplemented with scenario-based problems has been developed to teach the circulation system & hemodynamics and cardiac assist devices. Simulation has been shown to be an effective method for students to acquire knowledge and conceptual understanding of sophisticated systems. In this study, the model allows students to simulate a range of physiological conditions, study hemodynamic variables, and understand the conditions for using cardiac assist device interventions as well as its benefits.

The effectiveness of the simulation was assessed by asking students to solve a scenario-based problem and answering survey questions. The data from problem solutions indicate that after one 75-minute class, students are able to understand the mechanism of the human circulation system and the value of using cardiac assist devices. Student feedback to the survey rate the simulation model very positive in helping them understand human circulation and the proper use of a cardiac assist device.

I.Introduction

Circulation system & hemodynamics is one of the topics discussed in an undergraduate mechanical engineering course on bioengineering applications. Students enrolled in the class are seniors who are interested in learning the applications of mechanical engineering in biomedical field. In a 15-week semester, the course covers a range of biomedical topics and their engineering solutions. The course has one week dedicated to the study of blood flow dynamics which is directly related to fluid mechanics.

Students taking this course should have learned the fundamentals of fluid mechanics, including pipe flow (similar to blood flow in blood vessels) but only in the traditional engineering context. The challenges for them to learn circulation system & hemodynamics, especially within a short period of time, stem from: 1) a lack of understanding of the heart's function; 2) a lack of exposure to the context of human circulatory system and pathological/activity states; 3) minimum experience with several advanced concepts, including pulsatile flow, soft pipes, one-way valves in the circulation system, multiple stage branches pipe flow system, and cardiac assist pump. Although generally students can remember bits and pieces of the human circulatory system from the textbook, they are not prepared to analyze problems that require analytical thinking across human physiology and engineering contexts without a thorough understanding of how the above works. Their learning is limited to remembering facts, far from being able to

analyze and solve a problem desired for the course [2]. It seems that the biggest hurdle for students to reach high-level understanding of human circulatory system is the amount of information they need to digest in various health scenarios.

To help students better understand the human circulatory system, a simulation package is introduced to simulate a wide range of health scenarios where students can see how the major variables interplay. Meanwhile, to assist students navigate through the content efficiently, a Graphic User Interface (GUI) is developed for the simulation package to hide the extensive mathematical calculation so that students can focus on the relation between clinical symptoms and quantitative hemodynamic variables. It is worth noting that this GUI is developed by an undergraduate student researcher.

This paper will first discuss the benefits of the three components in our simulation package: interactive simulation, mathematical modeling with visualization, and real-world problems. Next, we will give an overview of the simulation package and GUIs for circulation system & hemodynamics reported in this study. Then, results from the direct and indirect student assessment will be presented, followed by the findings and discussion.

A. Interactive simulation and learning

A plethora of studies show that simulation modeling is an effective tool to teach complicated systems in science [[12], [15]], engineering [[2], [3], [4], [5], [9], [10], [11]], health care profession and medicine [[6], [8], [13]], and interdisciplinary subjects such as bioengineering [[13], [16]] and biochemistry [14]. Computational modeling, in particular, utilizes visual display of automated mathematical calculation to illustrate the inherent algorithms and constraints that lay the foundation for a sophisticated system. Magana and de Jong [2] summarize that computational simulations are primarily used in three ways: to teach students the art of modeling including system thinking, to impart the subject being modeled, and to illustrate the functioning a system via user interaction. From the perspective of cognitive psychology, the most important role of using simulation is to assist students in developing a mental model to replicate the system under study [17].

A mental model is one's hypothesis of how things work intrinsically as well as with its surroundings [17]. Also referred to as mental framework [18], it is the result of extracting salient ideas and building a coherent structure upon the emergence of new material. A mental model is the integration of abstract concepts with underpinning constraints and can be used to explain, predict, verify a phenomenon, or to reveal incompatibility with the existing hypothesis, therefore revise the current understanding into a more accurate mental representation of the system.

The best way to develop an accurate mental model is through interaction with the system [19]. Interactive simulation models allow students to experiment with the founding principles built in the system by trying out different variable inputs. Students can track and predict how the model would respond based on their initial understanding of the system. They can then compare the output results with their prediction, think about what causes the results [2], and then reinforce or correct their assumption. As Mollona [20] puts it, interactive computational simulation provides learners an environment to deepen learning.

B. Simulation modeling to reduce cognitive load

In learning circulation system & hemodynamics, students need to have a basic understanding of physiological parameters such as heartbeat, blood pressure, or cardiac muscle strength in order to relate them to a patient's clinical symptoms. Although they do not need to know the intricate details, the amount of information involved takes up students' much needed cognitive resources, leading to increased cognitive load [21, 22], and distracts them from focusing on the problem. The mathematic algorithms built in the interactive simulation model is designed to reduce such cognitive load. It converts user input to numerical values and displays them on a graphic user interface. The visualization of the data helps students make sense of the circulatory system by showing charts and graphs instead of listing a string of numbers in text. This way, students can allocate their cognitive resources on solving the problem.

As students test different variables in the interactive simulation model, they are exposed to a range of scenarios where the human circulatory system responses very differently. Analyzing how the system performs helps student achieve a deeper understanding of its complexity without dwelling into extraneous details.

C. Case and scenario-based learning and assessment

Engineering graduates are expected to solve real-world problems as they enter the profession. The ability to analyze a complicated interdisciplinary problem and apply engineering knowledge to practice is highly desired [23]. Nonetheless, traditional engineering education follows a twostep approach: imparting abstract concepts and assigning homework problems from the textbook. This approach does not help students make meaningful connections between their engineering training and real applications. When encountered with a real-world problem, students have difficulty seeing through the surface information and relate the problem back to their engineering expertise. Case-based instruction can bridge the gap between theory and application by bringing in authentic problems to the learning process. Cases and scenarios make technical learning more relevant to students. At the same time, it prepares students for the multi-faceted nature of often complicated problems they will face beyond school [24].

In this paper, we did not employ a full-scale case-based instruction, given that the topic of circulation system & hemodynamics takes only one week of the entire semester. We did, however, adopted real-world problems in the design of the simulation modeling and added a learning assessment using real scenarios.

We hope that the combination of interactive simulation, visualization of the mathematics, and working on scenario-based problem will push students to see the connections between engineering concepts in the context of medical problems, therefore prompts students to propose viable engineering solutions.

II. Methods

A. Simulation package and Graphic User Interface

Computer simulation is one important tool that has been widely used to study the interaction between the human circulatory system and an artificial blood pump due to low cost and its flexibility [[25], [26], [27], [28]]. The simulation results are based on the lumped parameter model of circulation system which uses electrical analogs to describe the characteristics of human cardiovascular system [[25], [26], [27]]. In those models, resistors represent the viscous property of blood flow, while inductances denote the inertial property of blood flow. Capacitors symbolize the elastic property or compliance of the vessel wall, and diodes are used to mimic the properties of one-directional valve. The volume flow rate is equivalent to the current in those models. One of such models focusing on modeling circulation system with a failing heart has been developed by one author of this manuscript using the popular software Matlab/Simulink [29]. The model (Figure 1) consists of seven stages of the circulation system in series, i.e. left ventricle, aorta, systemic arteries, systemic veins and right atrium, right ventricle, pulmonary arteries, pulmonary veins and left atrium. A continuous flow left ventricular assist device (LVAD), which provides supplementary blood flow when the left ventricle is weakened, is also included in this model. When the model parameters were varied, the model can calculate the time-varying cardiovascular system response (i.e. pressure, flow rate, volume, etc.) during different physical activities, at different pathological levels, with or without the assistance of a LVAD.



Figure 1. Electrical circuit analog of a human circulatory system with a left ventricular assist device [30]

In this simulation model (Figure 1), every time a scenario is created, a realm of parameters, sometimes up to 60 of them, will have to be updated. For example, the change from resting to mild exercise condition would involve the modification of heart rate, heart contractility during systole, peripheral resistance, and the intramuscular pressure waveform, etc. The shift from healthy heart to severe weak heart condition would result in another series of changes: heart rate, heart contractility during systole, heart compliance during diastole, ratio of systole vs. diastole,

peripheral resistance, etc. It is hard for non-medical professionals to identify the parameters that need changed due to lack of in-depth knowledge of the circulation system & hemodynamics. When it does happen, students have to make sure the variables entered are within a valid range at different stages of the model, which means they need to spend extra time working through advanced math modeling of circulation system.

To avoid overwhelming students in mathematical calculations, a graphic user interface (GUI) titled "Cardiosystem" was developed using Java FX. As shown in Figure 2, the user can create a scenario on the left panel of the GUI by clicking through the dropdown menus, sliders, or check boxes. Each selection corresponds to updating several more modeling parameters processed in the background. The simulation model then solves the values of all hemodynamic variables during the specified period. The middle panel displays the key settings of each scenario. Since the GUI allows the user to run up to three different scenarios per screen, the user can then select which hemodynamic variables (out of 21 in the dropdown menu) to study and compare the cause-effect due to induced changes on the right panel. In addition, the pressure-volume loop of the heart, the single most comprehensive measurement available for evaluating the cardiac functions, is displayed at the bottom of the left panel. Table 1 lists all the hemodynamic variables can be studied from the GUI.

LVP: left ventricular Pressure	LVV: left ventricular volume	AOV: aortic volume
AOP: aortic pressure	AP: arterial pressure	AV: arterial volume
CO: cardiac output	VP: venous pressure	VV: venous volume
OVP: pressure of non-	OVV: volume of the non-	MVP: muscular organs
muscular organs	muscular organs	pressure
MVV: muscular organs	IMP: intramuscular pressure	R _{muscle} : resistance of
volume		working muscle
RVP: right ventricular Pressure	RVV: right ventricular volume	PVP: pulmonary venous
		pressure
PVV: pulmonary venous	ω: pump speed	Q _p : pump volume flow
volume		rate

Table 1. Hemodynamic varia	ables from G	UI
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Figure 2. GUI of Circulation Simulation program (Cardiosystem)

B. In-class activities

In the 75-minute class, the instructor starts by giving a brief introduction of the model, then passes out a handout of three activities. Students then follow the instructions in the handout to complete the activities below using the simulation package through the GUI.

- Activity 1. Observe the pressure and flow rate at different locations of the human circulation system with a healthy heart in both rest and exercise conditions.
- Activity 2. Observe the pressure and flow rate with a weak heart in rest conditions without blood pump, and in rest and exercise conditions with a blood pump.
- Activity 3. Study the pressure-volume loop of the left ventricle in rest, exercise, weak, strong conditions.

The in-class activities were not collected or graded in FA 2018 as they were designed to familiarize students with the GUI. However, these activities are still built on each other with increasing level of complexity. In each activity, students are guided to select different pathological and activity scenarios by setting the values of heart rate (slider), strength level of left ventricle (dropdown menu), time for simulation (slider), whether to have an assist pump (check mark), and the corresponding pump control parameters (slider). Students are also guided in those activities to select the right hemodynamic variable(s) to display on the GUI and to make conclusions based on the results. The scaffolding of these activities makes it natural for students to revisit and compare with previous test results. Students were expected to complete activity 1 during the class and finish the other two activities after the class. It was brought to the instructor's attention that some students skipped activities 2-3 in fall 2018, likely because they were not collected or graded. Therefore, in fall 2019, the instructor collected activities 1-3 and assigned points for completion to motivate students to finish them before attempting a case study that was graded for correctness.

C. Solving a real-world problem

Three scenarios (Table 2) are given to students to work on after class. Those three scenarios are similar to each other but may have different heart conditions or baseline heart rates. Students can form groups of two and choose any one of them to work on. To keep it simple, we refer to the scenario study as case study, although it is different from the "clinical case study" commonly seen in professional medical science education. A sample case is provided in Appendix B. The case study reports are collected and graded.

Case I	Female patient with weak heart, 100 bpm in rest, study rest and exercise with
	the assistance of LVAD
Case II	Male patient with weak heart, 120 bpm in rest, study rest and exercise with the
	assistance of LVAD
Case III	Male patient with mild weak heart, 102 bpm in rest, study rest and exercise
	with the assistance of LVAD

Table 2. Three case studies

III. Results

In this section, we present assessments that directly and indirectly measure student learning. The direct learning assessment includes the graded case study report. The indirect learning assessment include the student feedback from the survey in Appendix A. The responses analyzed and presented below came from the 15 students enrolled in the fall 2018 class and 12 students from fall 2019.

A. Direct learning assessment

The case study report is graded based on the seven categories listed in Table 3. Each category is tied to a survey question or the overall understanding of the circulation system & hemodynamics, an indicator of whether students have developed a mental model successfully. For each category, students need to present both the correct conclusion and the corresponding supporting evidence from the simulation results to earn credits. The absence of either component will result in point deduction. Figure 3 shows the average of student performance by category.

	Concept Categories	Survey Items
1	Symptoms without pump	tied to survey Q4, Q6
2	Rest vs Exercise difference	tied to survey Q5
3	Proper plots/tables/data for conclusion	related to overall understanding of circulation system & hemodynamics
4	Benefit of pump	tied to survey Q8
5	Side effect of pump	tied to survey Q8
6	Long term use of pump	tied to survey Q8
7	Difference compared to a healthy person	related to overall understanding of circulation system & hemodynamics



Figure 3. Average class grades of circulation system & hemodynamics case study

As shown in Figure 3, on average, the 2018 class achieved 80% or more in the 7 of 8 categories, indicating their mastery in the major concepts. In both category 3 and 7, they achieved more than 90% of the max points, indicating an overall understanding of the circulation system & hemodynamics. The only category below 70% achievement is "long term use of the pump". It is also the category that students' score showing the largest variation.

The 2019 class achieved an average of 75% or more in 5 concept categories and received 82% in the case study report. It appears that students in both classes were challenged to obtain a balanced view between the benefit and side effect of using a pump as well as predicting the long-term effect of using it.

B. Indirect learning assessment

Students from the 2018 class used approximately 1.5 hours outside of class to complete the three in-class activities, almost half of what their 2019 peers spent — 2.75 hours. This difference may be partially contributed to students skipping activities 2 and 3 in fall 2018, likely because they were not collected or graded. The 2018 class also spent less time in order to finish the case study — 2.67 hours on average vs. 3.17 hours for the class of 2019.

The student survey uses a five-point scale, with 1 equals strongly disagree and 5 equals strongly agree. Student ratings of each question are presented in Figures 4-6. The results show that students feel the Simulation modeling/GUI is helpful to learning circulation system &

hemodynamics (Figure 4) and to understanding how the circulatory system responds to different scenarios (Figure 5). As shown in Figure 6, although students feel that simulation modeling/GUI still needs improvement in providing sufficient information, they also strongly agree that simulation modeling/GUI is better than text-based learning material on the same subject.



Figure 4. Student ratings on helpfulness of Simulation/GUI to understanding background concepts



Figure 5. Student rating on helpfulness of Simulation/GUI to understanding how circulatory system responds to changing conditions



Figure 6. Student rating on overall Simulation/GUI

Samples of student feedback to the survey and suggestions are included in Table 4. The comments also support the findings that although there is room for the simulation modeling/GUI to improve, students generally appreciate the chance to use it to assist the learning of circulation system & hemodynamics.

Table 4. Sample student comments from 2018 and 2019

None. Very good study case.Making graphs more modular, either adding more graphs or taking away or being able to
shrink/expand themThis is more of a software suggestion, but it would be nice if the minimum, maximum and
average values would be updated based on the zoomed in version of the plots.Easier way to view relationship between measured variablesPerhaps add a feature to adjust the levels of exercise to better see how exercise intensity
effects the cardiovascular system.Adding inputs such as weight, height, and gender would provide a more accurate study and
could make the simulations more interesting.The acronyms were sometimes confusing. Perhaps the full name would have been better to
understand what value I was looking at. Overall, I thought that the simulation went very well.Make it faster (2018); Improve the speed of simulations (2019)Maybe show where each vein/artery is and where it is pumping.

More class time to complete

My only complaint is that you can't save the X and Y parameters in the zoom window when you run a new calculation

Increasing the number of datasets and plots available would be useful.

Install the simulation on all the computers in the building

Make the program export all graphs so that you can view more than 3 graphs at a time. Review online notes more in class to relate variables to symptoms in patients.

Make it easier to store data and export results.

IV. Discussion and conclusion

A. Feedback from GUI developer

The undergraduate student researcher who developed GUI also enrolled in this elective course in fall 2018. Therefore, we are able to see both perspectives from him as the developer and the end user of the simulation. The student researcher found that the GUI development experience helped him tremendously academically. He stated that "Many of the issues and bugs within the GUI would seem overwhelming at first just like some of the topics in the upper level engineering classes. In order to resolve the issues within the GUI, I would have to take a step back and identify what the issue is and why it happened before fixing it. Similarly, by breaking down the engineering topics into small pieces I was better able to visualize them as well as (to) understand them better."

As the user of circulation simulation/GUI, the student stated: "The cardiovascular system is a very complex system that can take a very long time to understand it in its entirety. With the simulation I can look at different parameters or conditions of the system and look at how they affect the system. This is best done by entering the conditions of a healthy heart. Through this I can see the different pressures, volumes, and flows throughout the cardiovascular system over time. I can see the different cycles which are displayed on graphs.... Being able to see how the different parameters affect the pressure, volume, and flow rate is much more effective at understanding the cardiovascular system than being told, or reading an article, (about) how they change. Once I saw how the different parameters affected the system I was able to look at a case when a heart was weak and not able to support itself.... All of these effects are shown, not told, in the simulation which is much more effective at teaching anyone about the cardiovascular system as well as how to help make an unhealthy heart healthy."

B. Lessons learned

There was tremendous work involved in developing the simulation/GUI package. In our case, it took the undergraduate student researcher nearly two years working part-time on the project to complete the development. Nonetheless, it seems the efforts are being paid back given the positive student feedback and learning outcome. Results from the direct assessment demonstrate that students were able to analyze simple problems in circulation system & hemodynamics

efficiently, and they were able to provide viable solutions to a real-world case in just one week. In particular, students learned:

- The normal and abnormal (pathological) ranges of hemodynamic parameters.
- As pulsation of flow dies out in peripheral blood vessels, it gradually changes to a continuous flow in the capillary and veins.
- The effect of heart rate.
- The variation of heart and blood vessels during physical activities.
- The differences between stiffness of artery and of vein.
- The differences in pressure/volume of heart in various pathological states.
- The amount of work generated by the heart in each cycle.
- The beneficial and adverse effects of assist pump due to proper or improper use.

The authors feel that interactive simulation-based learning is very helpful to studying systems with large number of variables and complicated relationships. The adoption of GUI is especially valuable as it keeps the less relevant details out of sight, keepings students focused on the circulatory system in the simulation model.

The real-life case study is also a critical part of the simulation-based learning. Compared to classes of 2017 or earlier when the simulation/GUI package was used only for the in-class activities, the added case study in 2018 and on provided a test field where students need to demonstrate if they can make connections between engineering concepts and a real-world application. With this addition, students were able to see how the simulation/GUI package, the in-class activities, and a real-life problem line up together. The case study gives students a chance to practice what they have learned from the in-class activities, thus highlighted the purpose of learning. It also allowed the instructor to directly assess student learning in a way that was not possible before.

C. Utility of simulation for biomedical engineering students

Although this simulation model is developed for mechanical engineering students to learn hemodynamics, the authors feel this simulation package can also be used for biomedical engineering students with a different set of assignments.

Compared to mechanical engineering students, biomedical engineering students are more knowledgeable in cardiovascular system but less so in fluid mechanics. Therefore, the focus of this simulation model will be to help students practice their fluid mechanics skills. One of the possible uses of this simulation model is to study pipe resistance. Students can find the pipe resistance of a single arteriole given the average dimension of the arteriole, then compare the result to the derived total peripheral resistance (TPR) using the pressure and flow measurement from the simulation model, eventually figure out the total numbers of arterioles. This practice can be further extended to use the derived TPR in the exercise condition to calculate the change of the arteriole diameter during exercise.

For biomedical students interested in artificial organs, assignments related to the left ventricular assist device can be included. Students can use the measurements of the pressure and fluid rate to build a simplified dynamic model of the cardiovascular system, and then find the responding time of this model. Using the resultant responding time, students can predict how quickly the change of the pump speed will result in the change of flow rate in the desired location. If this idea is to be adopted, the GUI will need to be modified by adding the variation of the pump speed during simulation.

V. Limitations and Future Directions

The study has its own limitations. Since the course is offered only once a year as an elective for seniors, the enrollment is too small to conduct a control vs. treatment experimental study. Another challenge is that in order to do well in this class, students must already have a solid foundation in areas like engineering mechanics, fluid flow, system dynamics, and electrical circuits. The broad scope of knowledge base required by this course makes it infeasible to give a prerequisite exam covering all these areas at the beginning of the course. Instead, students complete mandatory prior knowledge reviews before each relevant topic is covered throughout the semester.

To find out if fall 2018 and fall 2019 students are academically equal, a simple *t*-test was conducted to compare the end-of-semester course GPA. The result revealed a significant difference between these two cohorts: while the 2018 students achieved a GPA average of 3.56 (median = 3.67, n = 15), the 2019 students completed the course at an average of 2.89 (median = 2.67, n = 12), p < 0.01. However, when the hemodynamic case study grades (Figure 3) were compared, 90.12% from 2018 (n = 15) vs. 82.67% from 2019 (n = 12), a *t*-test indicates p > 0.05, suggesting student performance in this assignment is not statistically different between the two cohorts.

Considering that the 2019 students also needed more time to complete the in-class activities and their lower reception of the GUI package, it appears that students from 2019 were not as prepared as their 2018 peers. In fact, they may have benefited from using the simulation package which helped them work on the case study assignment and achieved similar grades to the 2018 class.

In terms of the design of the simulation, the model is a lumped numerical model, thus can only give the pressure, flow rate after each stage of the circulatory system. For example, all the systemic arteries of the peripheral circulatory system are lumped together and represented by one pressure and flow rate. The model is not able to represent the pressure and flow rate of a particular artery, such as that of the femoral artery. In addition, several short-term features of the circulatory system were not modeled, including: 1) the delayed compliance effect of vessels; 2) the effect of sympathetic simulation and inhibition on blood vessel and heart; and 3) the baroreceptor feedback. The authors feel that it is not realistic for mechanical engineering students to learn those advanced topics in a week. One area that the authors would like to

improve is the capability of reproducing the Frank-Starling Law [30] of the heart using this simulation/GUI tool. At present, the cardiac output of this simulation/GUI is inversely related to the afterload (i.e. arterial pressure), different from the independent relation stated in Frank-Starling Law. It would be beneficial for mechanical engineering students to learn this important and permanent characteristic of the circulatory system.

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Appendix A – Student Survey

Please fill up this short, anonymous survey, to provide your feedback to the simulation modeling tool.

1. How long does it take you to finish the tasks below, not including the time you spend during the class?

	Less than 1 hour	1 hour	2 hours	3 hours	4 hours
Activity 1-3					
Case study					

2. Simulation modeling/GUI encourages me to identify the following critical features of circulation system & hemodynamics:

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
Pulsatile flow					
Compliance of blood vessel					

3. Simulation modeling/GUI makes it more straightforward to analyze hemodynamic variables of the following concepts:

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
peripheral circulation system					
pulmonary circulation system					

4. Simulation modeling/GUI helps me understand what is going on in the circulation system when a healthy heart deteriorates to a heart failure.

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
5, 5				5, 5

5. Simulation modeling/GUI helps me understand how the heart and the circulation system change under different physical activity intensities.

Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
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6. Simulation modeling/GUI helps me obtain a clear understanding of what symptoms heart failure patients would have and why.

Strongly disagree Disagree Neutral Agree Strongly Agree

7. Simulation modeling/GUI helps me relate 1D pipe flow (fluid mechanics) to the human circulation system.

Strongly disagree Disagree Neutral Agree Strongly Agree

8. Simulation modeling/GUI helps me understand the effects a well- or ill-regulated rotary blood pump can have on circulation system & hemodynamics as a LVAD (left ventricular assist device).

Strongly disagree Disagree Neutral Agree Strongly Agree

9. The visualization in simulation modeling/GUI provides sufficient information to learn how the circulatory system functions.

Strongly disagree Disagree Neutral Agree Strongly Agree

10. Compared to text-based learning material, simulation modeling/GUI makes it easier to visualize the differences between simulated results.

Stronaly disaaree	Disagree	Neutral	Aaree	Stronaly Aaree
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11. What changes would you recommend to improve the Simulation modeling/GUI with case studies?

Appendix B – Case study

Complete a two-page report of the selected case study using Cardiosystem. You may want to include plots from Cardiosystem to support your statement.

A female patient with congestive heart failure, i.e. "weak" heart, has a heart rate of 100 bpm at rest. The patient' left heart is unable to provide sufficient flow for the patient in the rest condition. What symptoms will you expect to observe in this patient?

Suppose the patient now received a rotary blood pump as a left ventricular assist device. Determine the proper control method to provide sufficient flow during rest condition. Sufficient flow is defined to be within 10% of the cardiac output that a "strong" heart with 75bpm can provide. Explain the benefit of pump using the related hemodynamic variables/parameters you studied in Activities 1-3.

Will you recommend the pump to run at the maximal speed or to just provide sufficient flow during rest condition? Explain why.

Will you recommend extended use (more than two years) of this left ventricular assist device? One factor to be considered is whether the extended usage will cause the fusion of aortic valve. How will you recommend the device to be used? Will the same setup be able to support the patient in the exercise condition? Explain why using the related hemodynamic variables/parameters you studied in Activities 1-3.

You can pick any controller for the pump. If you choose "constant speed or current setting", choose the pump speed or current to make the simulated CO to be close to that of a healthy heart. If you choose the "ADRC controller" or "P.I. controller", the controller's goal is to make the mean aortic pressure to track the reference value you specified. (Hint: the mean aortic pressure for a healthy person in rest is about 90mmHg, and is typically 10-20% higher in moderate exercise). What difference will you expect to observe in this patient as compared to a healthy person?