[3 mins] Introduction - Maria

[Maria is at front near powerpoint, Jennifer & Peter & Zhao & Jason is near whiteboard.]

Good afternoon everyone, today we will be conducting a workshop on the Verification & Evaluation stage of the systems engineering design process. My name is Maria and here are my colleagues. [Jennifer, Peter, Zhao, Jason introduce themselves in that order.]

> Before we start, does anyone know what is Verification & Evaluation? [Give out chocolates to those who answer.]

In today's workshop we will see how Verification & Evaluation are independent procedures that are used together to check whether or not your system design meets your customer requirements and how to decide the best design for this purpose.

We hope that by the end of today, you will understand that systems verification and evaluation techniques give you a systematic way of choosing one design option over another.

We will do this through a hands-on activity involving catapults. In the first 30 minutes, Jennifer and Peter will lead the activity on Verification. Then Zhao and Jason will guide you through Evaluation. Finally, we will conclude the session and discuss how we can apply Verification & Evaluation to our group projects. You can refer to the session schedule on the whiteboard.

Please feel free to ask questions during the discussion. I will now pass you to Jennifer who will talk about Verification. [Jennifer comes to front of presentation and Maria moves to click slides.]

[5-35 mins] Verification - Jennifer & Peter

<u>Theory - Jennifer</u>

Thanks Maria. Verification is the process of performing tests to determine if your system design meets the customer requirements. This is done by creating test methods for each of the attributes in the attributes cascade. Verification is an ongoing process done throughout the design of your system, which we will see in the following discussion.

There are 5 stages of testing: Analytical, Proof-of-Concept, System Prototypes, Operational Testing and Support Testing. For the purposes of this course, we are interested in the first three stages.

Stage 1, the Analytical model, is done at the conceptual stage of the design. This is an attributes cascade for a catapult design. [Read out what is in the attributes cascade briefly.]

> Does anyone know which attribute would require an Analytical model? [Give out chocolates to those who answer.]

If we have a look at an attributes cascade for a catapult, the tertiary attribute length of moment arm would not need a full prototype to test, and we can create a CAD model to show how a design, for example a spork for the catapult arm and bucket, will meet the attribute.

Some of the attributes such as correct angle cannot simply be verified using simulation or analytical models. We need to look at how this attribute works within our system. Here we use stage 2 Proof-of-Concept testing to create a crude prototype of the system with the aim of testing for the specific attribute. You can consider changing the variables, for example length of catapult arm or base of catapult, to verify the attribute. In this way, you can run a number of simulations without investing too deeply in your design.

> Can anyone else identify an attribute that can be verified using Proof-of-Concept? [Give out chocolates to those who answer.]

> How do you think we can test primary and secondary attributes? [Give out chocolates to those who answer.]

Generally primary and secondary attributes require a more developed prototype because all of the tertiary attributes will need to be met so that the higher level attributes are valid. In stage 3 System Prototypes, you create a working model of the system to look at the interrelationships of the different subsystems in a controlled testing environment.

Stage 4 Operational testing looks at the product out of the controlled testing environment in the real world, and stage 5 Support testing looks at providing support to the design while it is public use.

The multi-stage process for verification shows how this is an ongoing process. If the tertiary attributes were not verified, a flaw in a component may lead to failure of the primary attributes of the design. Conducting verification is an iterative process that builds resilience in your system starting from Customer Requirements to the System Interface, as shown in the Vee-Diagram. Correcting a flaw in the later stage of a design is much more costly and time-consuming than identifying it in an early design stage.

We will illustrate a simple verification process using System Prototypes testing to verify our primary attributes. Our case study is on Lord of the Rings. We have heard word that an orc army is planning to attack the city walls. Knowing that you have completed ENGN2225, Gandalf has chosen you, a military engineer, to design a catapult. Gandalf wants a catapult that is accurate, long range and is low cost. You have designed five alternative prototypes, and you will need to test them to find the best one. I will now hand it over to Peter, who will be leading the activity.

Application - Peter

Thanks Jen. Now with the knowledge we have, we need to come up with the testing methods to determine whether our prototypes meet our primary attributes. A simple procedure should cover these four points:

1. Which attribute are you testing? This is from the customer requirements: accurate, long range and low cost.
2. Who does the testing? For example, what qualifications must they have?
3. A repeatable procedure that anyone can follow and obtain the same results.
4. What is the pass/fail criteria? This is the benchmark of the standard catapult, which we provide to you here.

[Show a table of the benchmark for the standard catapult according to the customer requirements.]

[Relate back to House of Quality.]

You need to find a testing method to verify the distance the catapult can throw, how accurate it is, and the cost. This should be three testing methods, one for each attribute. The materials you can use in the procedure are on the front table.

Different testing procedures can result in different outcomes of the best design. For this reason, we will need to split the project groups so that each member can witness how this works. Remember how you received a chocolate at the start of the tutorial? We ask you to find your chocolate brand and sit on a table together. Milky Way where Maria is, Mars where Jennifer is, M&Ms where Zhao is, Snickers where Jason is. [Facilitators move to each table.] You have 3 minutes.

[Put 3 minute timer on screen.]

Now with these methods ready, it's time to test them with the methods that you just came up with. Warning: in 6 minutes we will swap catapults so that you get to test at least two alternatives.

[Around 5 minutes, remind groups that we will swap catapults. Milky Way swaps with Mars, M&Ms swap with Snickers, if a group is too slow, give another group the trebuchet.]

With the testing procedures you have created, you are ready to move on to the next step: Evaluation. But before that, let's get back to real life (because this is very important for your own project).

> [Ask each group of their method for testing accuracy.]
> How do you think the differing methods will affect the design output?
> How to make the result repeatable?

> Are the results qualitative or quantitative? For example, with accuracy, the measure of probability for how many times it will hit the target can produce different design outcomes depending on the sample size.

These are a important things that you need to consider when applying verification to your own project.

This case study is a very simple example. The testing procedure for your project will need to consider more steps such as system safety and system interoperability. You may also test for multiple attributes within the same procedure. Furthermore, you should consider if your design meets the Australian standard, and search for whether or not testing specifications and regulations exist for it. For example, safety requirements in wheelchairs for use in public are covered by the Australian Design Rules.

And now, with your testing procedure, you can move on to the next step Evaluation, lead by Zhao.

[35-55 mins] Evaluation - Zhao & Jason

Theory - Zhao

Thanks Peter. Evaluation is the process of making a decision for your design based on the design criteria we had from the customer requirements. It should assist you in improving the design, rather than validating it.

There are many different types of evaluation methods and evaluation criterion that we can implement, such as these ones listed on the slides. These evaluation methods give us an idea of how our design meets the design criteria, how to improve the design, and how we select the best design. Hence choosing the appropriate evaluation method is very important.

Among these methods, we have direct ranking, systematic elimination, and comparison across different alternatives or across a standard. Then we have four mathematical techniques, all of which focus on how confident the decision maker is about their design. The maximax assumes absolute optimism of the decision maker, and it evaluates the design under the assumption that everything goes perfectly well. On the other hand, the maximin assumes a scenario where everything that can go wrong will wrong, and hence is called pessimism. For the laplace criterion, please don't be confused with the laplace transform in mathematics and electrical engineering. This laplace criterion means that the decision maker is 50% confident and 50% not confident, and this puts it half way between maximax to maximin criteria. Lastly, the Hurwicz criterion goes one step further and actually assigns a number called the coefficient of confidence.

These evaluation techniques will be studied in greater depth in ENGN2226, but for the purpose of this tutorial and this course, we will only focus on the direct weighting method and the comparison across a standard.

- Relate back to House of Quality (Benchmarks + Targets, Comparisons)
- Comparisons will be across five design alternatives. [Show five catapult designs on slides.]
- In your project, you can compare how your design performs against different alternatives.
- Talk about how customer and design requirements, FFBD, design attributes, pairwise should be referred and related to during the evaluation process
- Pass on to Jason

Activity - Jason

Thank Zhao. In the next activity, I will hand out one sheet of evaluation matrix to each group. So what you guys need to do is fill up the table with the design requirements, and at least 2 design concepts on the top of the table. Then you will need to give a score to each attribute according to their relative compliance. I will give you around 10 min to do that and later on I will ask how you come out with the final decision.

[10 min for the activity]

So let's talk about it. Can I know what's your highest score design? (ask one group then point to other group and ask 'is it the same?') How about the other 2 catapult design? Is the score around the same? That's because if you have 2 design that have really close score, then maybe it will be useful to discuss with the customer. So, do you think that's the best design for a catapult?

If no, why? If yes, why?

So actually I ask that question is because the highest score actually did not reflect how they fulfill the customer requirement. Instead, you should use another evaluation method such as a benchmark comparison to support your decision. Let's say we use comparison across a standard. If the standard requirement for a catapult is that the range must exceed 1.5 m, then some of designs will fail that criteria. From there we could improve our design to meet the requirement. Or in another case is that the customer have a budget limit, then they cannot afford such an expensive catapult. This might also change the decision on which design to use for final solution. At last, you have to make sure that you always meet the customer requirement when you doing the evaluation process. To relate back to your group project, you can use this process to modify or improve the design or maybe communicate with the customer. And now i will pass it to Maria to finish up with the conclusion.

[55-60 mins] Conclusion - Maria

Thank you Jason.

> From the activity today, what have we learnt about verification? Why do we do it? When does it occur in the design process? [Give out chocolates to those who answer.]

We have learnt that verification is an ongoing progress that allows you to build resilience in your system through a number of tests that ‘validate’ how the system performs against the customer attributes.

In your project, it will be complex to create your own testing method to validate the attributes. An idea can be to research into the components of your system to determine whether or not it satisfies the criteria. If your solution is available on the market, perhaps look at use cases or customer feedback to determine its applicability to your problem. The design can also be created in engineering programs such as ANSYS.

> What have we learnt about evaluation? What is the difference between verification and evaluation? [Give out chocolates to those who answer.]

We learnt that evaluation is the process of making a decision for your design based on the design criteria we had from the customer requirements. It should assist you in improving the design, rather than validating it. This is because if your customer requirements change or if the market changes, your design may no longer be the best alternative to the solution.

In your project, you will apply evaluation by creating a weighted evaluation matrix similar to the one we completed during the activity today. With this information you can now add two more rooms to the House of Quality. These are Benchmarks + Targets and Comparisons. A completed House of Quality can look like this.

This is the end of our tutorial. We hope that you have enjoyed our facilitation and that you now understand how systems verification and evaluation techniques give you a systematic way of choosing one design option over another.