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Going beyond concepts: Nurturing practices in science & engg

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What do we want our students to be able to do?

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Solving a problem - Each one type one

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You are participating in an electric car race in which you are required to design an electric car of weight 5kg with wheel diameters of 4" that can traverse a track of 50m in less than 5s.

Can you use the motor of a vacuum cleaner to build this car?

In order to solve this problem, what knowledge and skills does one need?

1) can start with concepts, but think what else is required
2) be specific, go beyond saying "problem solving" skills

What do we want our students to learn?

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- ‘Understand’ content: concepts, hierarchy and interconnectedness

- Solve problems
- Model phenomena
- Design systems
- Analyze, troubleshoot
- Critique, Argumentation

- Work in teams, communicate …

(ABET, NGSS, NMEICT pedagogy project, Sheppard 2009, Pellegrino 2006…)

What do scientists & engineers do in professional practice?

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- Integrate, apply concepts
- Formulate questions
- Solve complex, ill-defined problems
- Design systems
- Create, test, refine models
- Multiple representations
- Design experiments
- Formulate and test hypotheses
- Evaluate claims, designs, feasibility..

(Jonassen 2000, Sheppard 2007, NRC 2012)

What are *practices* ?

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".. behaviors and actions that scientists engage in as they investigate and build theories about the natural world, and that engineers use as they design and build models and systems"

(Next Generation Science Standards, US)

Examples –
hypothesis generation & testing, data representation and interpretation
design thinking, estimation, troubleshooting, computational thinking

Examples of practices in your domains?

More about practices

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- Require integration of domain knowledge and processes in specific ways, for example:
- Could have broader applicability, for example: estimation of other physical quantities (energy, weight …)
- Alternate names : thinking skills, scientific habits of mind, trans-disciplinary habits, 21st century skills, ….

(Pellegrino & Hilton, 2012; National Research Council, 2012; Mishra, Koehler & Henrikson, 2011)

Raise your hand if you have heard any below

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Student: "I studied/know the concept really well, it's just that I cannot solve this problem"

Teacher: "I showed students N examples of how to apply it, but few could apply it in a different context on the test"

Employer / industry / McKinsey report:

"Most engineering graduates don't have the necessary skills and we have to retrain most entry level candidates"

Practices are not automatically developed

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- Challenging for novices
- 'Knowing' domain concept ≠ applying practice
- Students are not able to apply such practices to solve problems after instruction in disciplinary content alone
- Students need to apply practices reflectively and critically

Implication:

Address teaching & learning of practices explicitly

(Salomon & Perkins 1989; Eckerdal et al 2006; Rivera-Reyes & Boyles, 2013; Dym et al, 2005; Atman et al, 2007; Etkina et al, 2010; Moore et al, 2013).)

Our Project – two related goals

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- What is the cognitive process of learning of practices?
  - leads to theory of developing expertise

- How to support students' learning of practices?
  - leads to design of learning environments, teaching strategies, learning tasks, scaffolds

Method – Design-based research, iteratively addresses both goals

The LEAP Model (LEArning of Practices)

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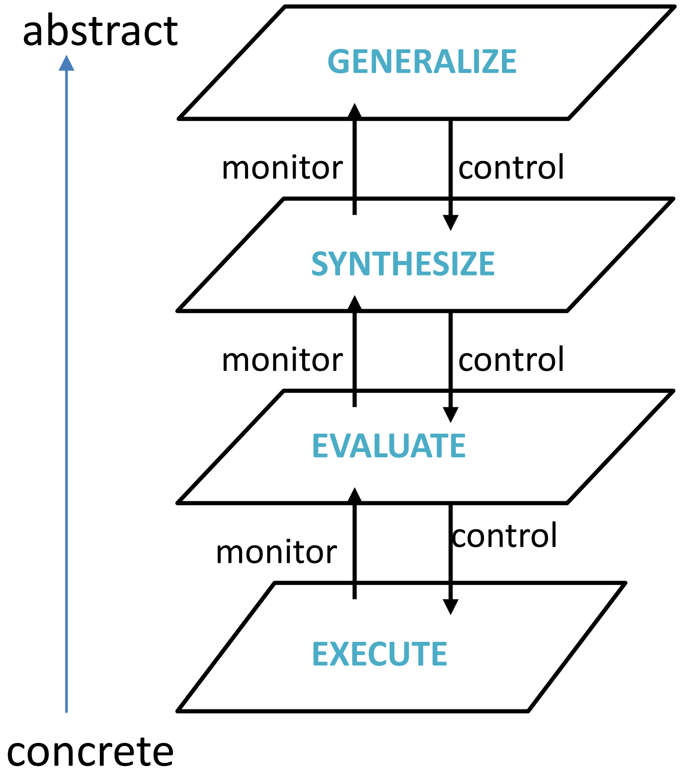

The practice gets developed as the learner goes through cognitive tasks at progressive levels of abstraction.

Progression between levels is triggered by monitoring and control.

Example: Estimation

(PhD thesis of Dr Aditi Kothiyal, 2019)

Recall – estimation problem

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You are participating in an electric car race in which you are required to design an electric car of weight 5kg with wheel diameters of 4” that can traverse a track of 50m in less than 5 seconds.

Can you use the motor of a vacuum cleaner to build this car?

In order to solve this problem:

Concepts, relationships, principles – power, force & motion

Understanding multiple interconnected systems (electrical & mech)

Engineering knowledge (eg efficiency of motor)

Operating conditions

Decision making

….

Learning goal: Estimation

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An analysis to determine a physical quantity in a physical system to some level of accuracy without complete information.

Estimation is a common practice in engineering:

Initial step of design, evaluate the feasibility of an idea, eliminate candidate design solutions, plan projects

Estimation is complex, ill-structured, many unknowns and uncertainties, yet make key decisions – research challenge and teaching challenge

Understanding the cognitive process of estimation

Study 1
Experts - engineering faculty & professionals
Cognitive ethnography, microgenetic analysis

Study 2 / 3
Novices – BTech students
Cognitive ethnography /Lab study; Microgenetic / Thematic analysis

Understanding the cognitive process of estimation

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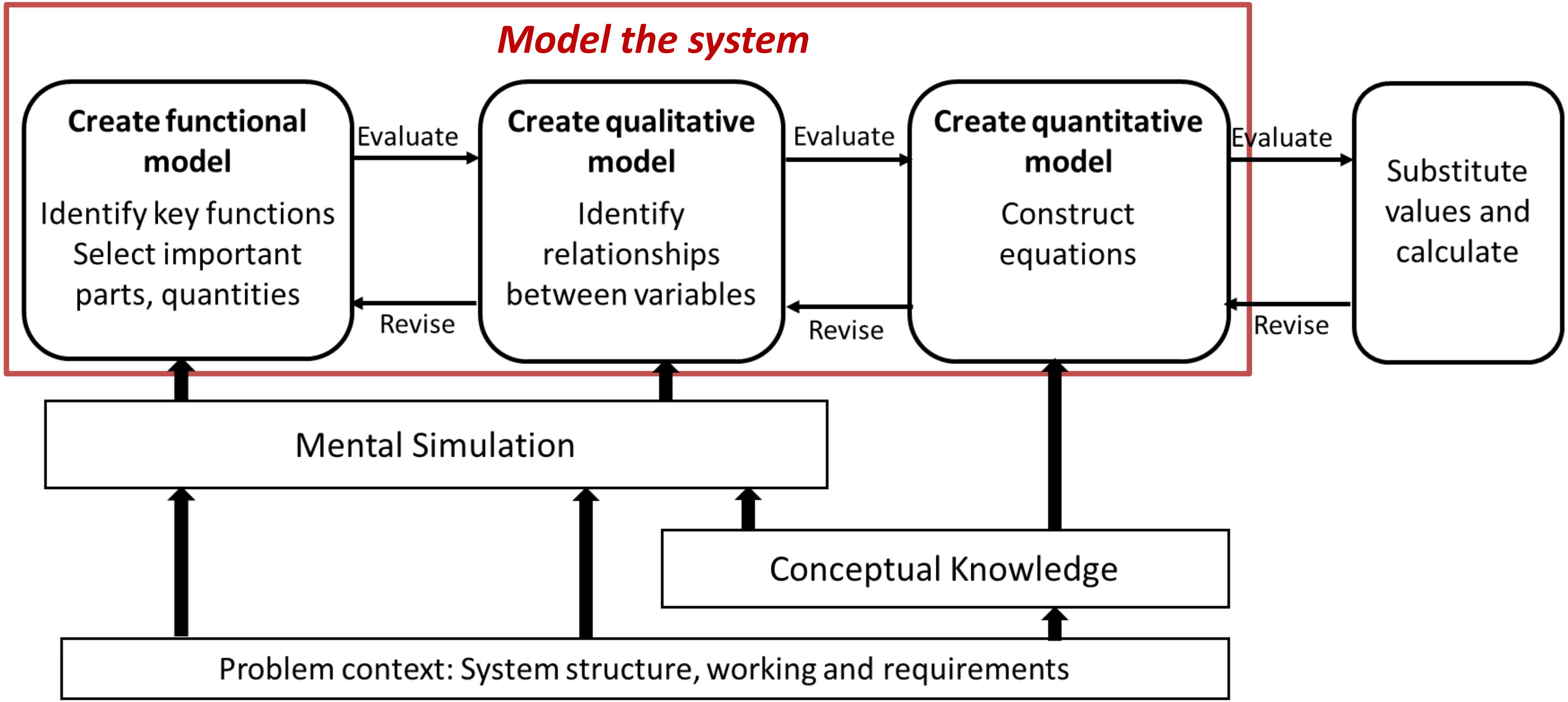

Understanding the cognitive process of estimation

- Experts build models (3-phase) and do mental simulation
- Problem context integral in solving problem

- Novices search for mathematical models, begin with equations
- Novices need scaffolds for building the model of the system, for imagining and simulating, and to apply concepts in the problem context

Implication - Design the learning environment to support process

Zooming in – process involves levels of abstraction

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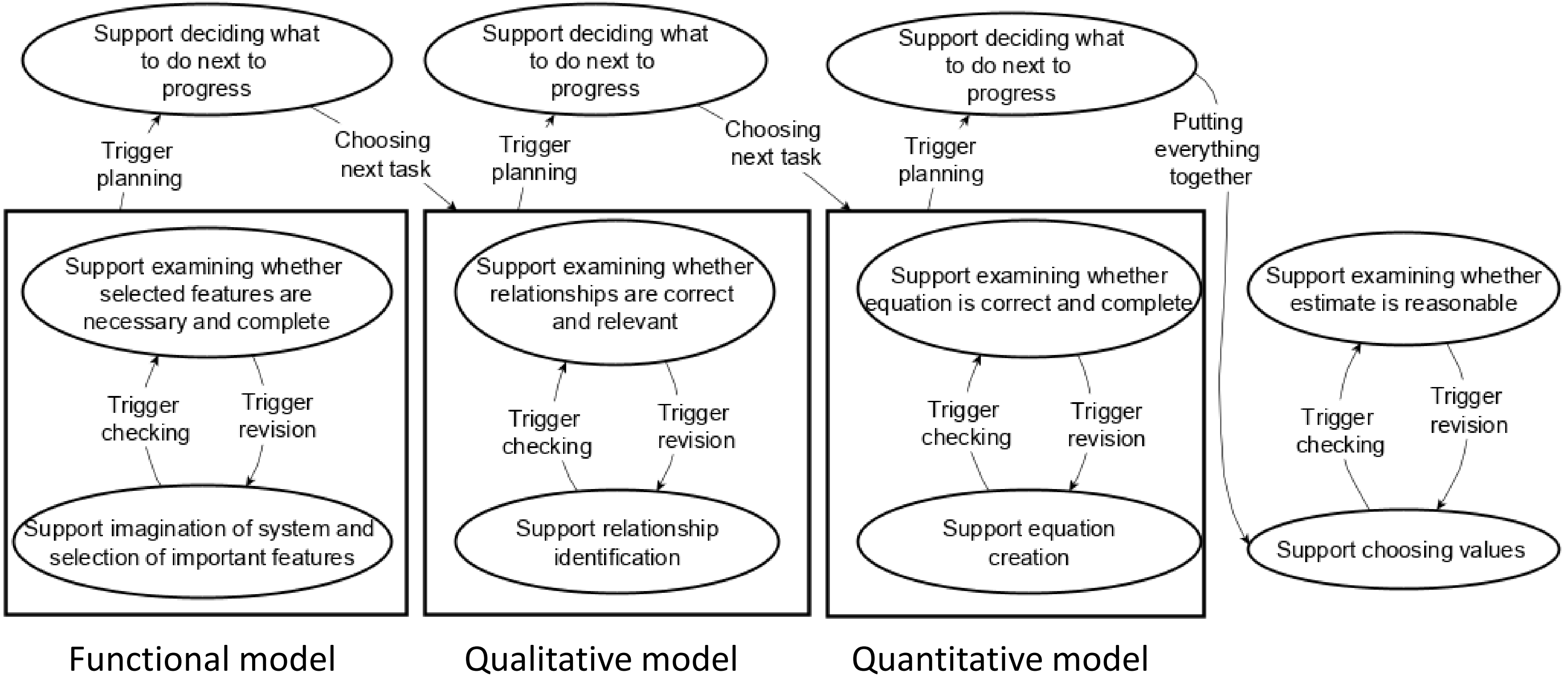

Design the learning environment with supports at each level

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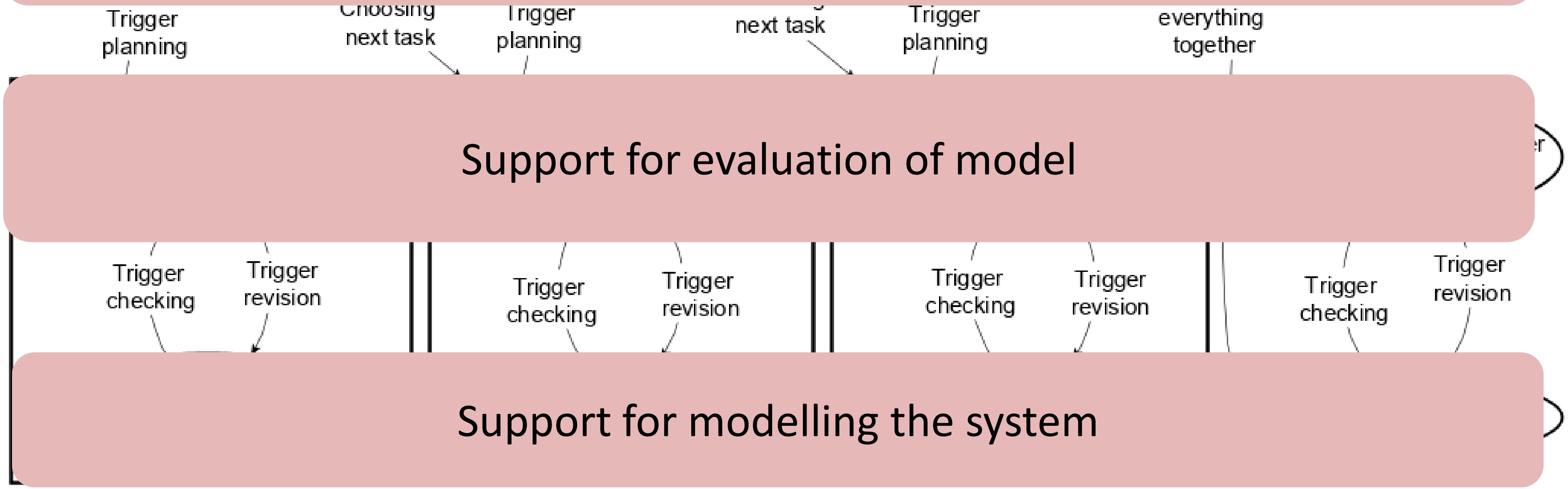
Support for planning and monitoring



Support for evaluation of model

Support for modelling the system

Technology-enhanced learning environment

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- Computer-based software
- Problems on estimating physical quantities - Power, motion, force
- Self-learning / can be used in lab guided by an instructor
- Interactive simulations
- Questions, text-boxes
- Prompts, pop-up hints
- Feedback and basic adaptation
- Tools for graphing, diagramming, calculator

TEL environment: MEttLE

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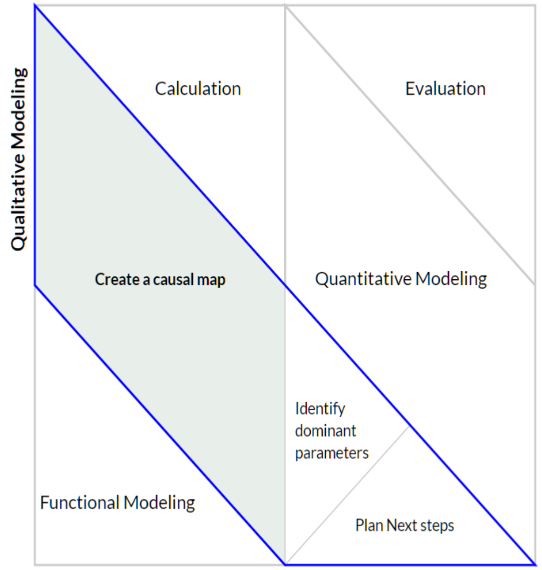
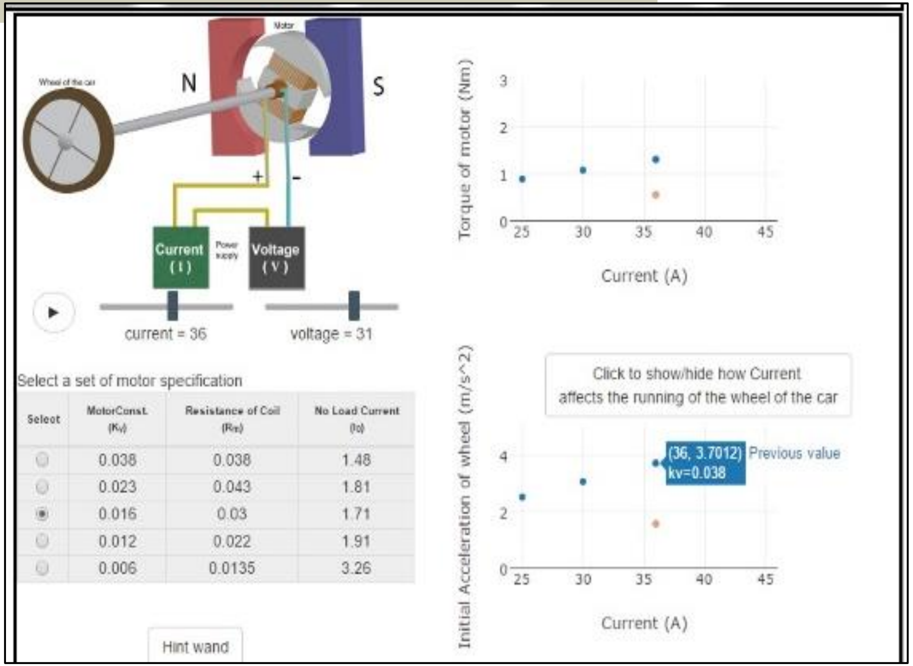
MEttLE | Simulator | Calculator | Info Center | Scribble Pad | Problem Map

What are the parameters that affect the dominant mechanical power required?





How does MEttLE support learning of estimation?

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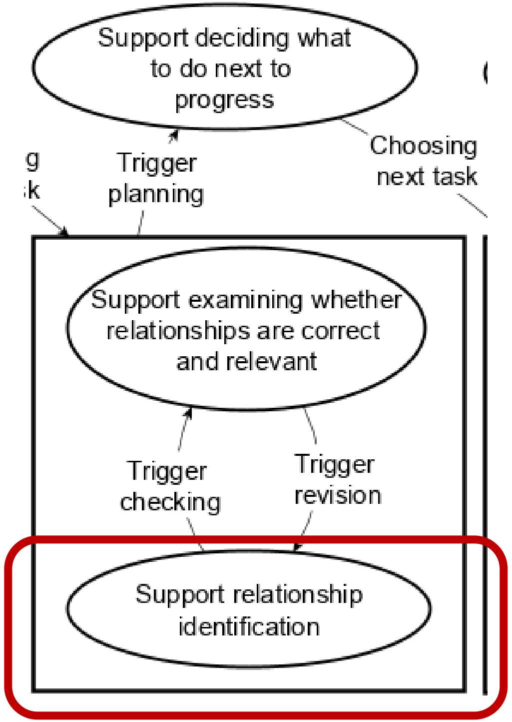

Qualitative model

Building the model

How does MEttLE support learning of estimation?

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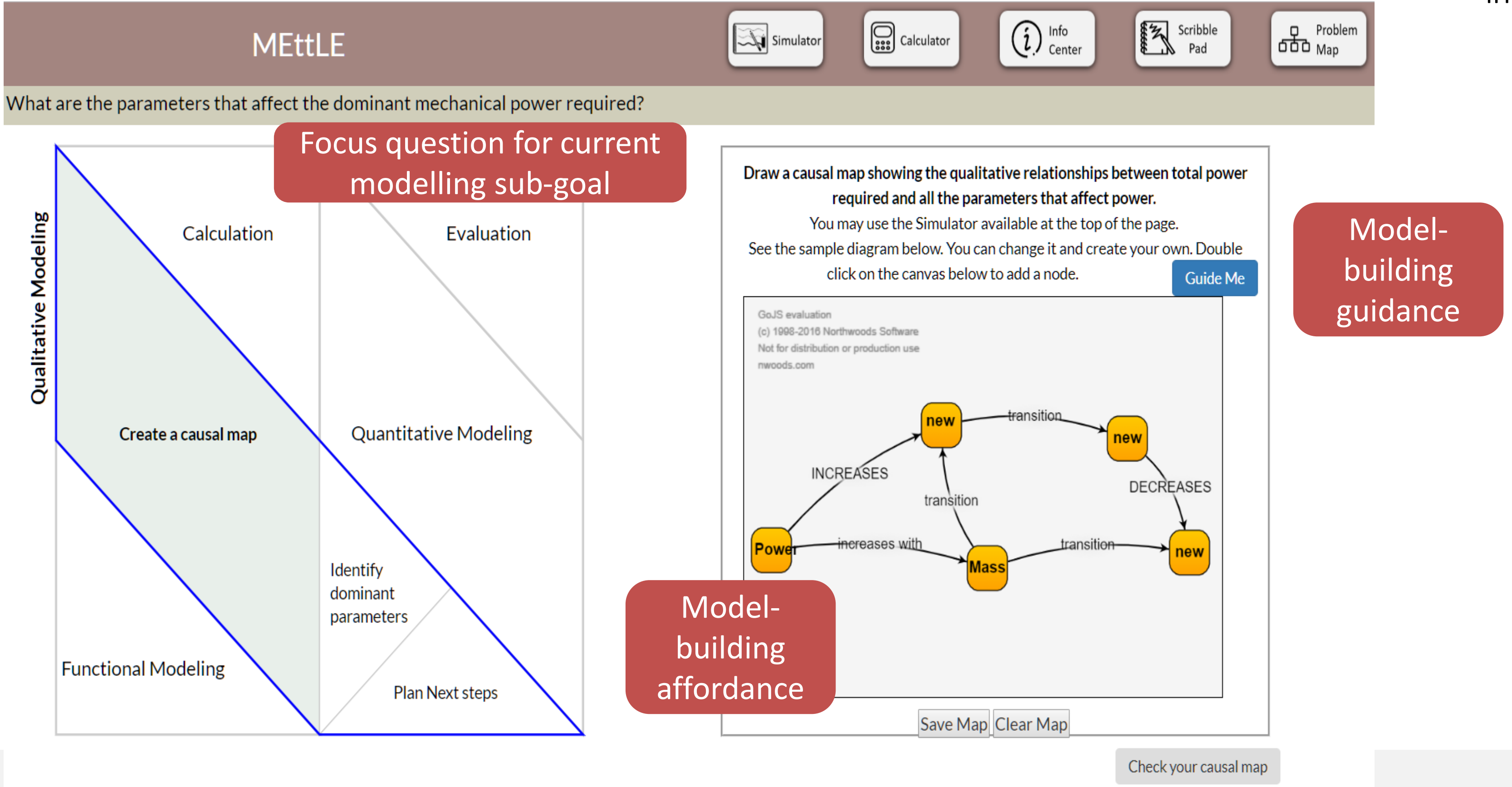

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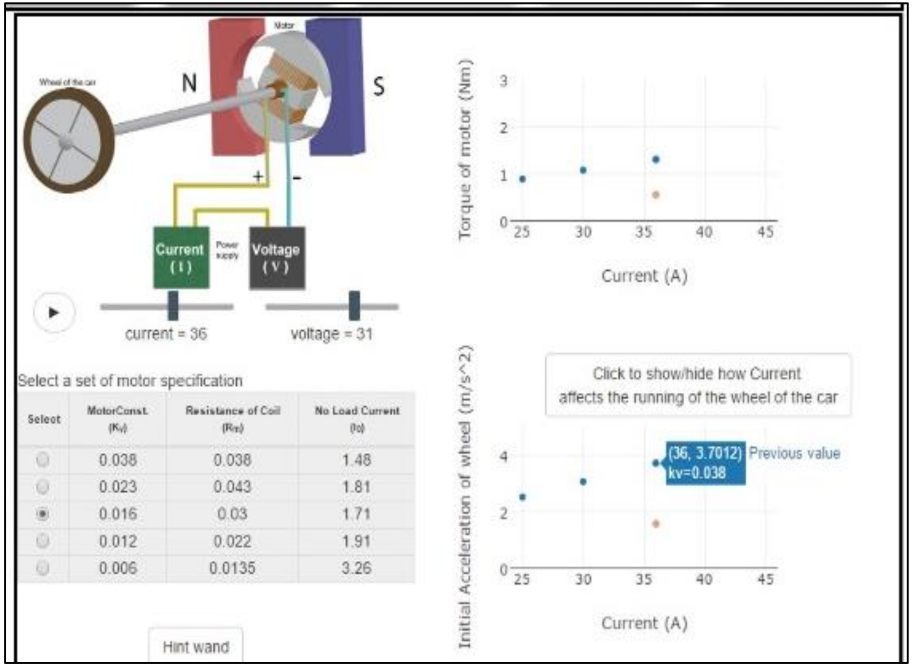
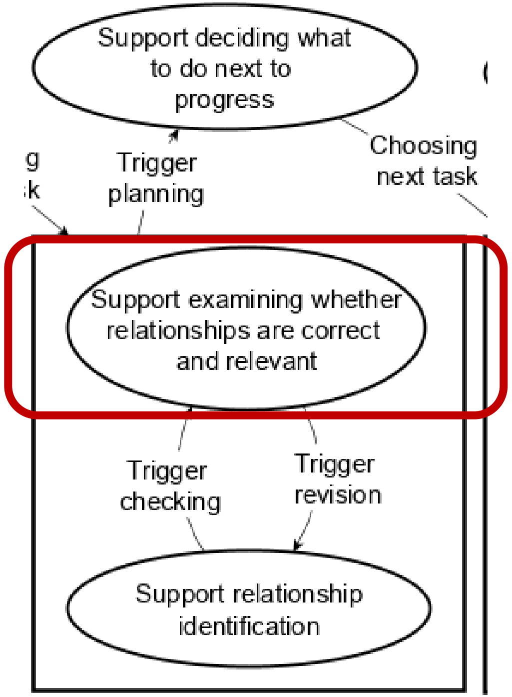


Simulator – support for imagination, identifying dominant parameters, relationships between variables

How does MEttLE support learning of estimation?



Qualitative model

Evaluating the model

How does MEttLE support learning of estimation?

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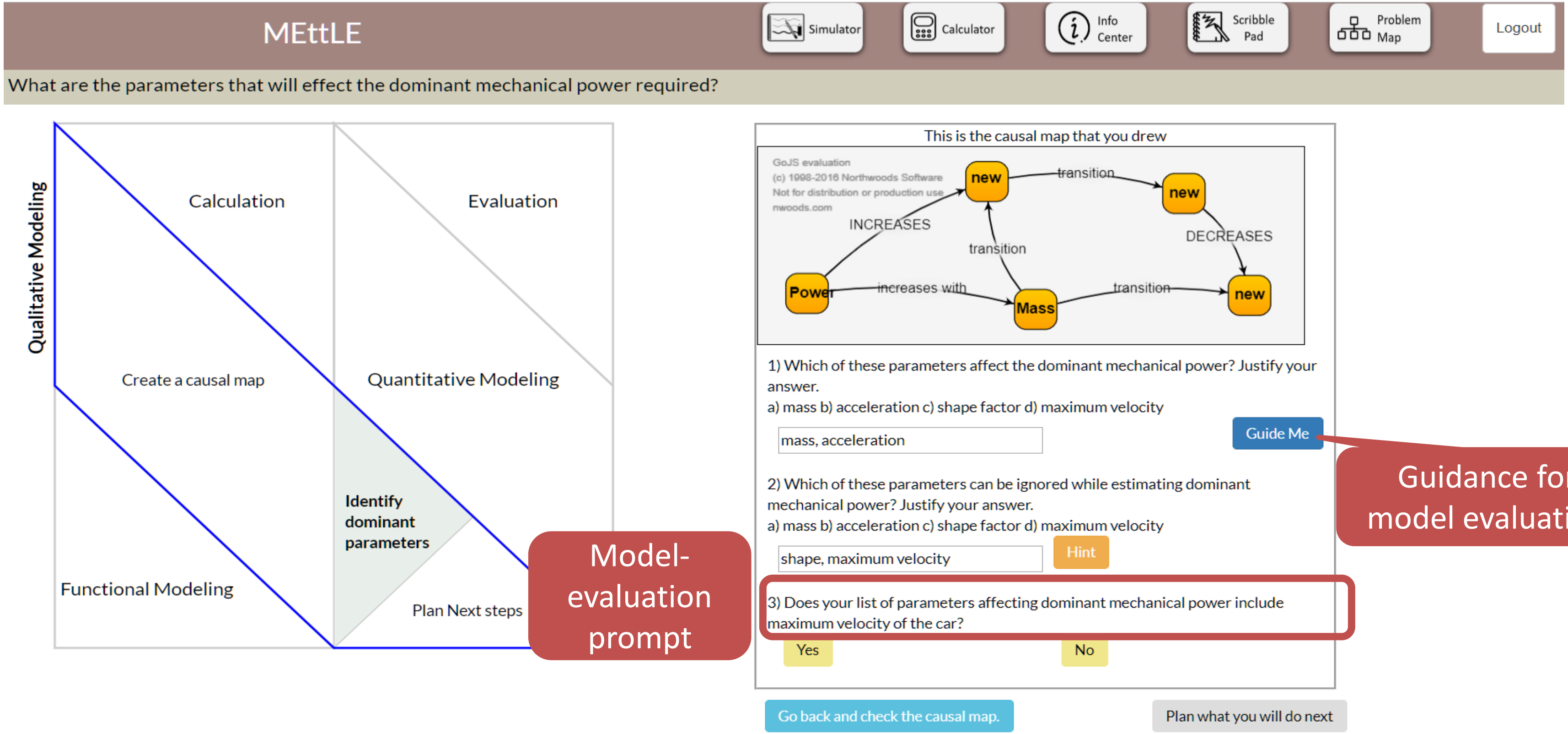

Guidance for model evaluation

Model-evaluation prompt

How does MEttLE support learning of estimation?

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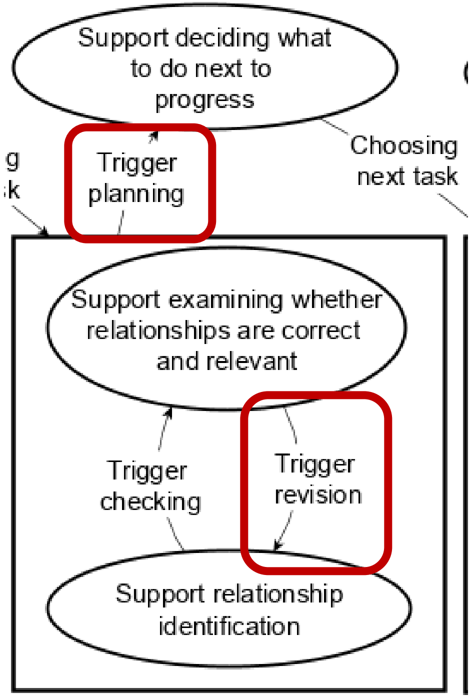

Qualitative model

Metacognitive triggers

How does MEttLE support learning of estimation?

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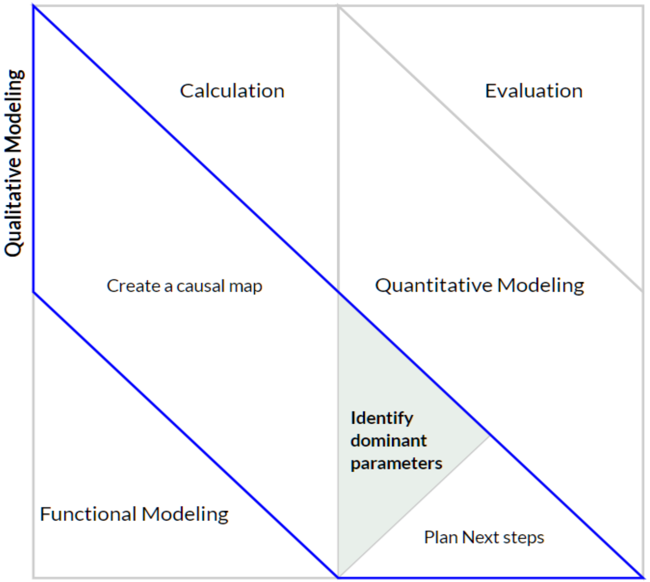
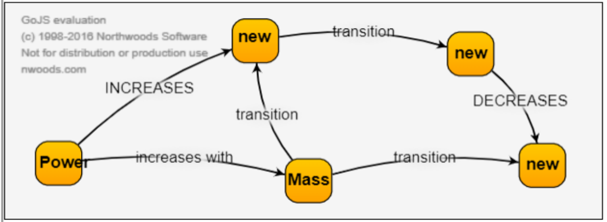
MEttLE

Simulator | Calculator | Info Center | Scribble Pad | Problem Map | Logout

What are the parameters that will effect the dominant mechanical power required?



This is the causal map that you drew



1) Which of these parameters affect the dominant mechanical power? Justify your answer.
a) mass b) acceleration c) shape factor d) maximum velocity

mass, acceleration

Guide Me

2) Which of these parameters can be ignored while estimating dominant mechanical power? Justify your answer.
a) mass b) acceleration c) shape factor d) maximum velocity

shape, maximum velocity

Hint

3) Does your list of parameters affecting dominant mechanical power include maximum velocity of the car?

Yes No

Trigger revision

Go back and check the causal map.

Plan what you will do next

Trigger planning

Takeaway

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The learning process involves:

- Levels of reasoning, from concrete to abstract
- Metacognitive processes (planning, monitoring, control)

Design of LEs should include:

- Tasks at each level and corresponding scaffolds to do the task
- Metacognitive prompts to support the learner to accomplish tasks, and to trigger revision or plan next steps
- Scaffold identification of appropriate conceptual knowledge and its application in the practice

Example: Micro-Macro thinking

(PhD thesis of Dr Anura Kenkre, 2017)

Learning goal: Micro – macro thinking

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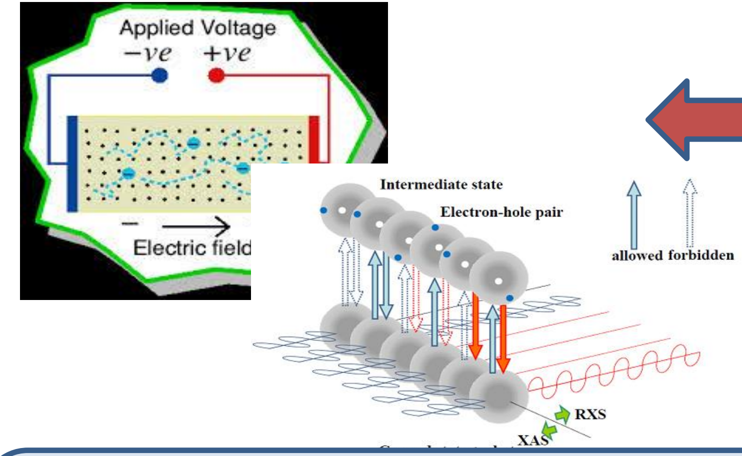
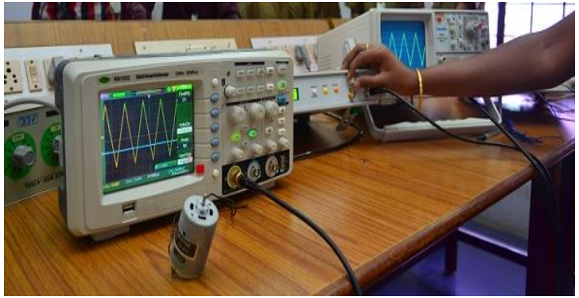
Microscopic
(invisible elements, molecular level)



Macroscopic
(directly observable)



Establish a link between invisible /theoretical variables (micro) and its corresponding manipulable variables (macro) in order to predict the behavior and functionality for any given system

Practices involved in micro-macro thinking

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- Identify, describe patterns in the micro world
- Model the behavior of the entities in the micro-world
- Make a prediction of macro-world variables based on micro-world model
- Decide whether prediction and actual experimental outcome agree/disagree
- Identify assumptions and implications
- Revise model as required

Design of TEL environment: Mic-O-Map

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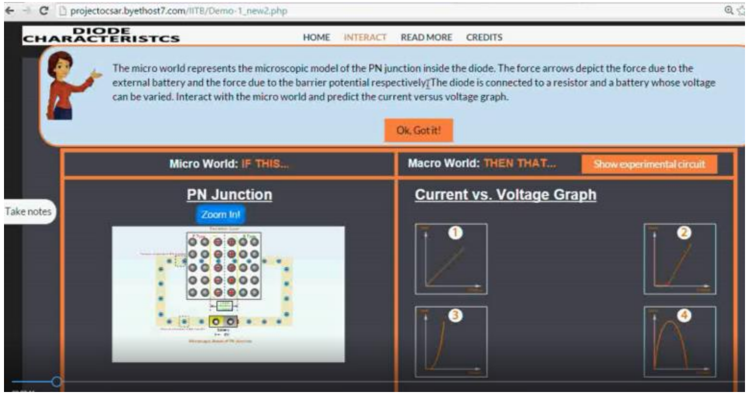

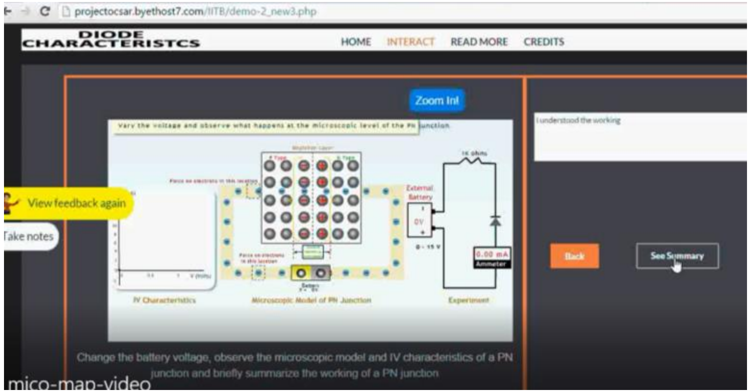

- *Micro*: electron motion, barrier potential, # e’ns in conduction & valence band
- *Macro*: voltage, current, doping, ..

Mic-O-Map pedagogical features

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Microscopic Observations Macroscopic Predictions

Learning activities

- Guided questions, navigation prompts
- Variable manipulation to understand relationships
- Model microscopic behaviour (e'n motion, barrier potential, …)
- Prediction tasks – V-I graph, justify based on microscopic model
- Analysis tasks – analyze macro outcome, correlate with micro model

Scaffolds

- Multiple representations
- Pedagogical agent
- Constructive feedback
- Metacognitive prompts

Design: Mic-O-Map

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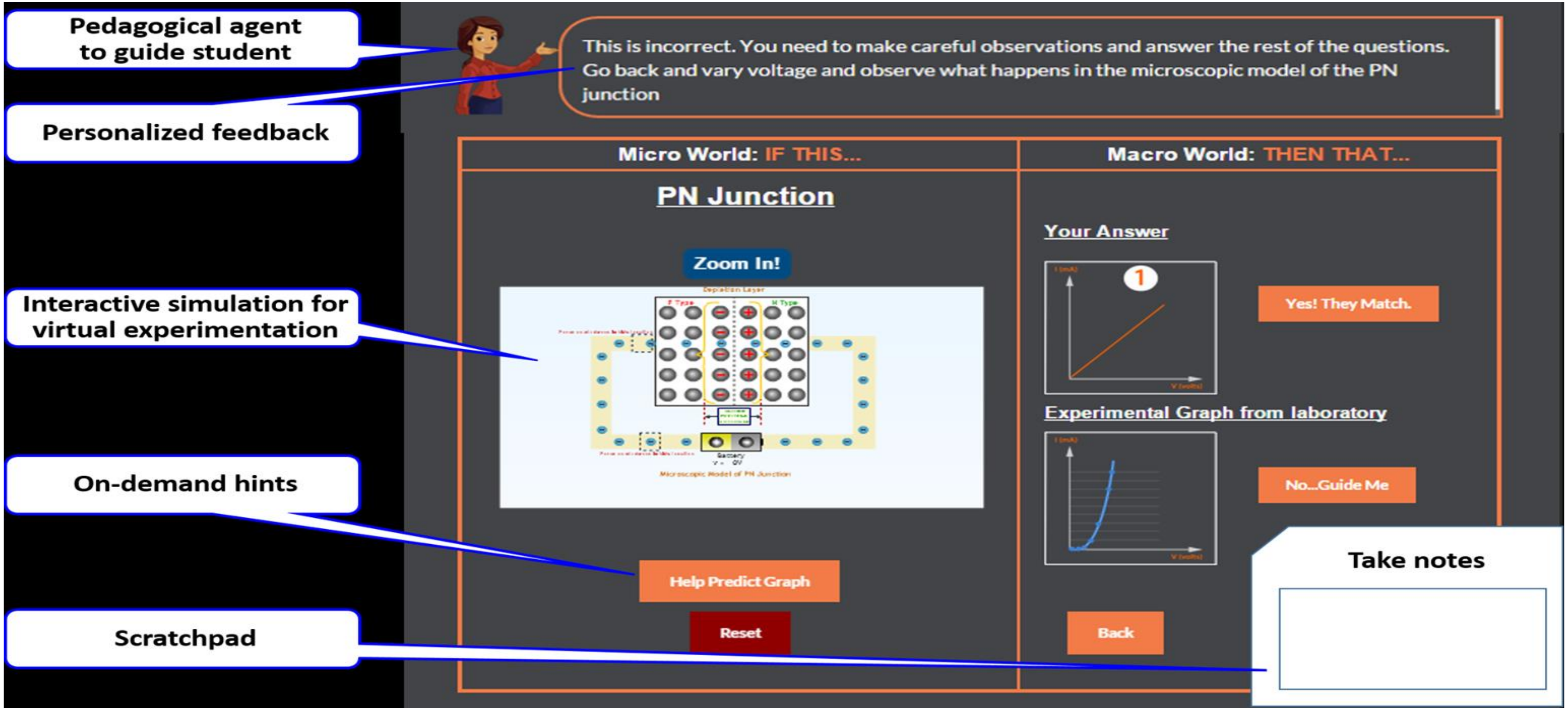

How does Mic-O-Map support learning of practices?

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Tasks and scaffolds in Mic-O-Map foster students to do “productive actions” at various levels of reasoning. Students who did these actions developed expertise in the practices of micro-macro thinking.

Synthesize:
Integrate micro-macro link

Relate multiple reprsnts (ckt, e’n motion, graphs)
Write summary considering micro & macro aspects
Metacognitive – Reflection prompts

Evaluate:
Strengthen micro-macro link

Decide if prediction matches experiment outcome
Revise prediction if necessary
Metacognitive – Assertion & evaluation prompts

Execute:
Establish micro-macro link

Manipulate simulation variables, make prediction
Guided wayfinding to do tasks
Metacognitive – Prompts to repeat if unable

Do students develop practices?

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Research studies: Total 250 students, 6 topics
[2-grp quasi-expt (N=73), single group pre-post (N=135), repeated measures (N=29)]

Findings:
Statistically significant improvement in describing observed patterns, devising explanations, making predictions with correct reasoning, deciding outcome matching

Back to the LEAP model

The LEAP Model (LEArning of Practices)

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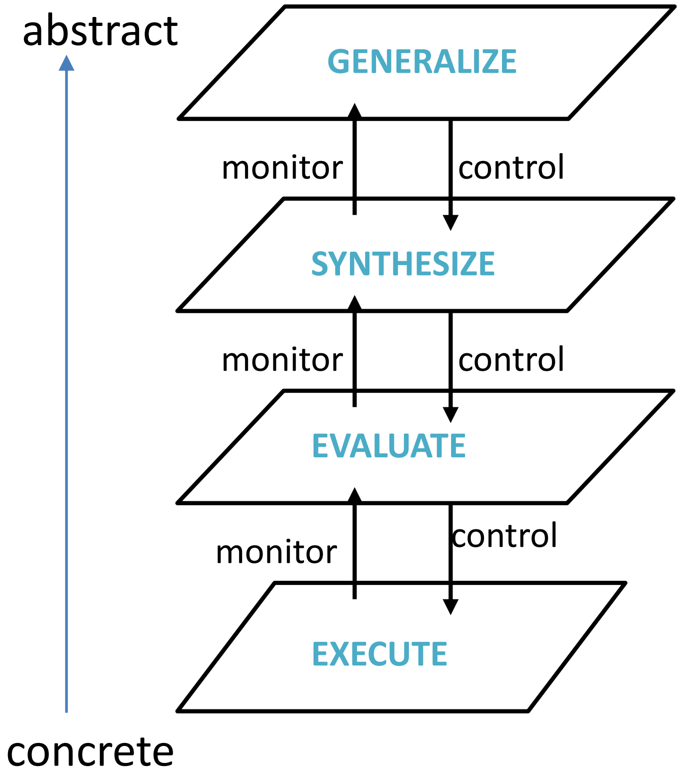

The LEAP Model (LEArning of Practices)

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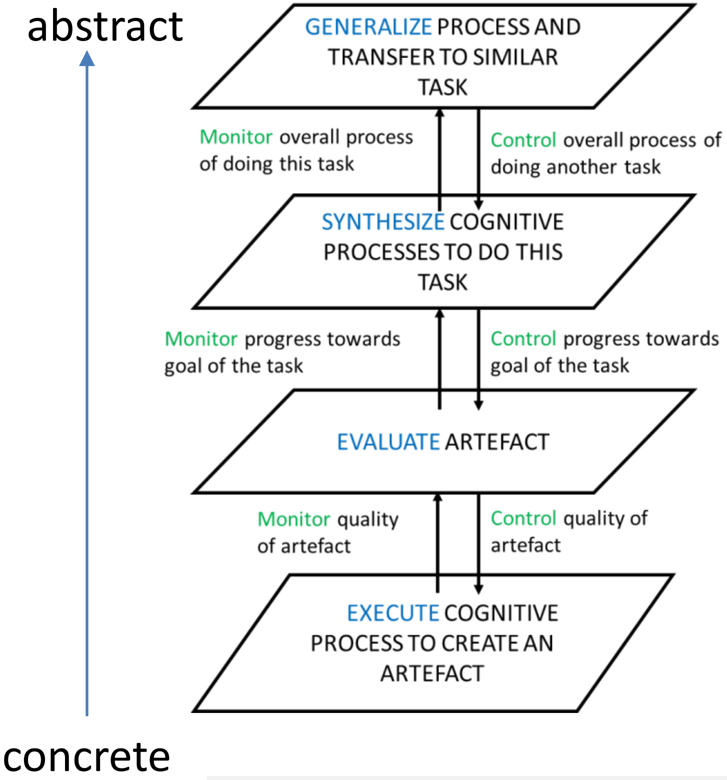

How will you solve the next problem?

How did you solve this problem?

Evaluate: does your answer make sense?

Do this task.

If you are teaching a practice

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Use the LEAP framework to design the learning experience:

- Make learners do tasks at progressively higher levels of abstraction – Execution, Evaluation, Synthesis, Abstraction.
- Give meta-cognitive prompts to take learners from one level to next.

Provide scaffolds during learning:

- Support learners to complete a task.
- Provide constructive feedback frequently.

Provide sufficient and diverse practice:

- Expand scope of problems from near areas to far areas.
- Gradually fade the scaffolds to make learners independent.

How does LEAP help learners?

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Standard route:

………..

UG:
- Solve many back of chapter problems, some toy projects
- Comfortable with execute
- Use domain concepts in pieces
- Practices are implicit

→

Grad school / industry entry:
- Do more projects, bigger, initially apprentice with seniors
- Adept in concrete execution,
- Start independently evaluating
- Get familiar with abstraction

→

PhD end, industry experience:
- Formulate, plan and manage projects
- Integrated domain & practice
- Strong in monitoring and control

LEAP help learners leap

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LEAP model

UG:
Solve many back of chapter problems, some toy projects
Comfortable with execute
Use domain concepts in pieces
Practices are implicit

→

Grad school / industry entry:
Do more projects, bigger, initially apprentice with seniors
Adept in concrete execution,
Start independently evaluating
Get familiar with abstraction

→

PhD end, industry experience:
Formulate, plan and manage projects
Integrated domain & practice
Strong in monitoring and control

Make application of practice explicit at progressive levels of abstract
Support and show how domain concept is incorporated in practice
Scaffolds & feedback to demo plan, monitor, control
Sufficient and diverse contexts of application (near to far)

TEL environments for learning STEM practices

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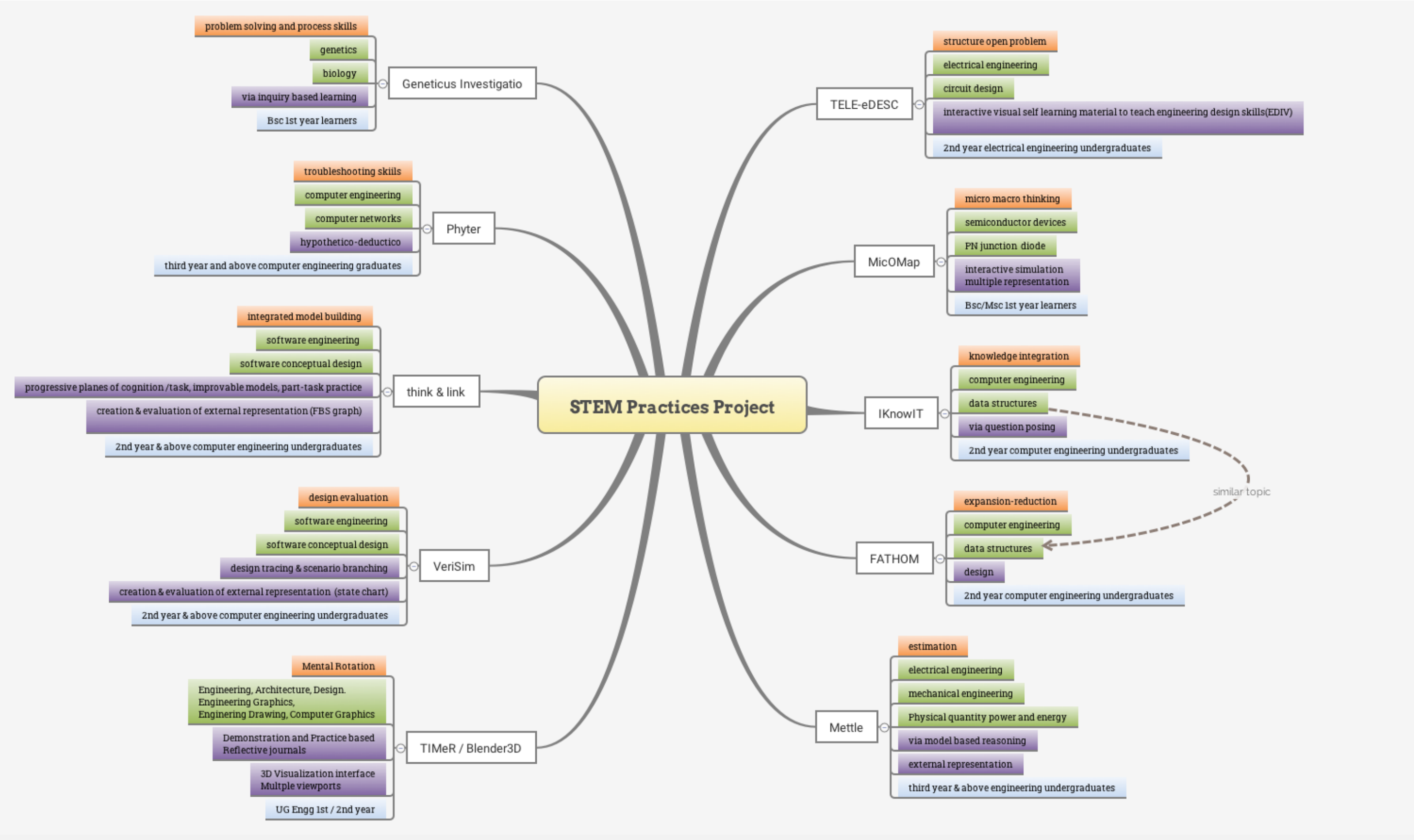

Contribute

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1) Identify a practice relevant in your domain / area of expertise. It should be something you want your students to develop.
2) Think of a problem or question related to that practice.

Email these to us ☺

3) Going ahead - Imagine you have to teach it (for ex 2nd / 3rd yr Btech). Apply the LEAP model and come up with associated tasks and prompts

- Identify the key pieces or actions to apply that practice, - create Execute level tasks where something (eg a fig) is generated
- Identify how one can check the goodness of the generated artefact – create Evaluate level tasks
- Create Synthesize level tasks – ask students to integrate the pieces, and summarize how they solved the given problem
- Come up with a different problem for the same practice and ask students how they will solve the new problem
- Design prompts for students to monitor, control, plan

Thank you!

To use our TEL environments

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- (as is) For same topics, same problems: Go to our website or email me
- ~10 learning environments –
  - micro-macro thinking in electronics, estimation for power problems, troubleshooting in computer networks, conceptual software design, evaluation of software design, expansion-reduction thinking in data structures question posing in data structures, hypothesis testing in genetics
- Use our TEL environments for your topics
  - Identify tasks at different levels of abstraction
  - (may need to) create corresponding simulation
  - Put tasks into TEL environments

(email me if you want to do the above)

Literature: Learning & teaching of practices

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Science education research, Discipline-based education research, Engineering education research, Learning sciences, Cog

- Inquiry labs (Krajcik et al, 2001; Hofstein et al, 2005, Hofstein & Mamlok-Naaman, 2007 and many more)
- Integrated courses with scientific abilities at the core (expt design, multiple representation) (Etkina …., SM, …et al, 2006).
- Iterative modeling for productive disciplinary engagement in engg design (Dasgupta, 2019).

Methodology: Design-based research

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ANALYSIS & EXPLORATION | **DESIGN & DEVELOPMENT** | **EVALUATE & REFLECT**

Problem: Learning of thinking skill in STEM topic

ANALYSIS & EXPLORATION

- Literature: How to support learning of thinking skill? Of topic?
- Analyze cognition of experts & novices in applying thinking skill

DESIGN & DEVELOPMENT

Conjecture learning pathway

Instantiate learning environment design - learning activities, supports, using technology affordances

EVALUATE & REFLECT

Test the design: Analyze data, interpret results.

<u>Is desired learning happening?</u>

Build / Extend theory

What is the learning mechanism?

<u>How does design support learning?</u>