DEVELOPING AND TESTING A NEW COURSE FOR TEACHING THE FUNDAMENTALS OF BUILDING PERFORMANCE SIMULATION

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ABSTRACT

During the past decades building performance simulation (BPS) tools have become complex. Alternate methods are offered for resolving many of the significant heat and mass transfer processes and energy conversion systems. At the same time, modern user interfaces allow users to quickly ascend the learning curve to operate tools in order to produce simulation predictions, although the prediction of accurate results is perhaps becoming more challenging. In a previous paper we proposed a continuous learning cycle that includes exposure to theories and the application of tools from the start for effectively teaching BPS. This involves having the students actively experiment with BPS tools to support the theoretical study of modelling and simulation theory. This paper presents the pedagogical basis, the intended learning objectives, and the procedure for such a course. This contains a series of simulation exercises we have developed for supporting the teaching of models for simulating heat and mass transfer processes and convective heat transfer pertinent to the indoor environment. It also presents the feedback provided by the first two groups of students that have piloted these exercises.

INTRODUCTION

In an earlier paper (Beausoleil-Morrison and Hopfe, 2015), we proposed a framework for teaching building performance simulation (BPS) through a complete and continuous learning cycle to address the need for new teaching methods in this domain (Clarke, 2015). This learning cycle includes guiding students on methods for interpreting, scrutinizing, and verifying simulation predictions as well as a study of the underlying models, simulation methodologies, and their inherent simplifications and limitations. One of our goals is for students to become cognizant of the impact of using tool default methods and data, and the myriad sources of uncertainty. With this framework we encourage students to experiment with tools to investigate these impacts in a recursive manner with the formal teachings.

This framework was motivated by the following observations we had made based upon our experience at delivering courses at the university post-graduate level and in the delivery of professional development training sessions:

Obs-1 Theory underpins the application of BPS, and through experiential learning a deeper understanding of the subject is possible.
Obs-2 It is relatively easy to train an architect or engineer to generate simulation predictions with any research or commercial tool.
Obs-3 It is quite difficult (even for experienced users) to produce accurate results.
Obs-4 Simulation predictions are often insufficiently scrutinized by users.
Obs-5 Users often place too much faith in their simulation tools.
Obs-6 The user is the greatest source of uncertainty.

We have now developed a university-level course based upon this learning cycle. This course is currently being taught in a semester format as an engineering postgraduate course at Carleton University, and in a block-week format in Master of Science modules at Loughborough University.

The current paper explains in greater detail the rationale for our learning cycle and its teaching methods and describes the course. We commence with a review of pedagogical literature that informed the development of our framework. This leads into a presentation of the intended learning outcomes for the course. We then present our learning cycle and explain how we have implemented this structure into the course, including describing the teaching and assessment methods employed. We provide examples of the exercises we have created for two of the (in total 20) course's topics to provide the reader with a clear understanding of our approach, and discuss the feedback we have received from two groups of students who have trialed these exercises. The papers terminates with concluding remarks.

PEDAGOGICAL BASIS

How students learn

The *learning pyramid* in Figure 1 illustrates that people learn best when they are actively involved in the learning process. The retention rates given in the figure are estimated by the National Training Laboratories Institute for Applied Behavioral Science. For example, people retain only about 5% of what they are taught by lecture, and only about 10% of what they have learnt from reading. In contrast to these traditional or passive teaching methods, people retain much more with teaming or participatory teaching methods, such as when they are engaged in group discussions, when they practice what they have learnt under the guidance of a coach, or, especially, when they actually apply the new knowledge in a realistic setting.

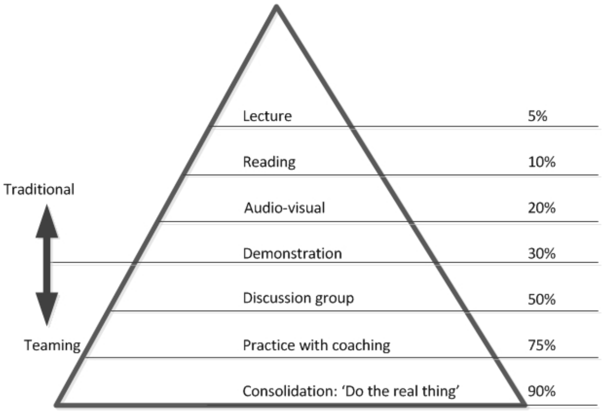

Figure 1: Learning pyramid showing average retention rates (adapted from National Training Laboratories Institute for Applied Behavioral Science)

Biggs and Tang (2007) provide an explanation for why lectures can be so ineffective. While concentrated effort is required to follow a lecture, the act of passively sitting and listening tends to lower the student's concentration. Furthermore, the attention of a student can typically be maintained for only about 10 to 15 minutes. They point out that although lectures can be effective for presenting information (but not as effective as reading), they are quite ineffective for stimulating higher order thinking, such as hypothesizing, evaluating, and reflecting.

Felder (1988) pointed out that students learn in many different ways. Some respond well to teaching styles that emphasize abstract concepts, whereas others respond better to teaching styles that emphasize facts. Some are more visual, while others more verbal. He put forward a conceptual framework that included 32 learning styles, and proposed that instructors adopt a range of teaching techniques to accommodate the learning styles of all students. This includes providing a balance of concrete information and abstract concepts; and emphasizing both fundamentals along with practical problem solving. He also recommended the use of many media and modes of instruction as opposed to relying heavily upon traditional lectures.

Aligning teaching and evaluation methods with desired outcomes

In designing teaching and evaluation methods, Rowntree (1987) suggests that we consider what kinds of outcomes or results are desirable. For this, it is important to distinguish between: (1) factual knowledge and its application; and (2) procedures used to achieve the results.

Students must develop factual knowledge. In the BPS domain, this could be developing an awareness of the mathematical models and simulation methods that have been developed to predict, for example, transient conduction through opaque wall assemblies. But such factual knowledge of the equations and solution methods is not sufficient on its own; it is necessary to put this knowledge into practice.

Students must develop–through practice–an aptitude for appropriate procedures to apply the factual knowledge. This is far more important than simply achieving correct results. This is an important consideration in designing simulation exercises and evaluation procedures for teaching BPS.

Biggs and Tang (2007) promote a form of *outcomes-based teaching and learning* called *constructive alignment* that immerses students in an environment that requires them to use learning activities most likely to lead to the intended outcomes. This starts with an explicit statement of the intended learning outcomes (ILOs) that tells us what the students should be able to accomplish, and how well they should be able to do it. This is followed by designing teaching/learning methods that engage students in activities that link directly to achieving the ILOs. The third essential feature of constructive alignment is developing methods for assessing how well the ILOs have been achieved. Throughout this entire process, it is imperative to align the teaching/learning activities and assessment tasks to the ILOs.

Experiential Learning Theory

Experiential Learning Theory (Kolb, 2014) helps explain how experience is transformed into learning and reliable knowledge. This theory encompasses four distinct learning modes which are employed in a recursive cycle: *concrete experience*, *reflective observation*, *abstract conceptualization*, and *active experimentation*. It is important to note that unduly focusing attention on one of these modes of learning at the expense of others will adversely affect the complete learning cycle. As argued by Kolb, this cycle affords opportunities for creativity and ownership of learning.

INTENDED LEARNING OUTCOMES

The course we have developed is targeted at students who wish to develop an in-depth knowledge of the BPS field. It responds to the six observations we made in the introduction by emphasizing the teaching of physical principles and underlying mathematical models employed by BPS tools.

As discussed in the previous section, an ILO is a means of outlining what the student will be able to do at the end of the course in terms of knowledge and understanding, approach, and skills. Therefore, in designing ILOs, it is necessary not only to understand what is central to the topic, but also to be able to summarize, present, and teach it to others. We make use of Bloom's taxonomy (Bloom, 1956)–which classifies forms and levels of learning in the cognitive domain, from remembering to understanding to applying, and then to analysing, evaluating, and creating–to develop the ILOs.

We have divided the ILOs for the course into knowledge and understanding, intellectual abilities, and transferable skills, as outlined below.

Knowledge and understanding

On completion of the course students should have developed knowledge and understanding of:

ILO KU-1 The physical models that have been developed and implemented into BPS tools for treating the significant heat and mass transfer processes.

ILO KU-2 The simplifications inherent in these models and the mathematical methods used to simulate them, and appreciate the necessity for these simplifications.

ILO KU-3 The relative importance of input data, the uncertainty associated with establishing these inputs, the potential for error propagation, and the impact this can have upon simulation predictions.

Intellectual abilities

On completion of the course students should have developed the intellectual abilities to:

ILO IA-1 Realize the implications of these simplifications upon prediction accuracy and develop the ability to select appropriate models, simulation methods, and BPS tools for a given analysis.

ILO IA-2 Realize how BPS can be effectively employed in the building design process, and understand the limits of the technology.

ILO IA-3 Analyse, critically appraise, and solve simulation problems and generate, collect, and interpret numerical and/or qualitative data.

ILO IA-4 Identify their own learning needs, plan to meet these needs, and evaluate the learning outcomes.

Practical skills

ILO PS-1 On completion of the course students should have developed the practical skills to model and simulate the thermal and airflow performance of a building.

Transferable skills

On completion of the course students should have developed their skills to:

ILO TS-1 Communicate effectively, graphically, and in writing.

ILO TS-2 Demonstrate numeracy, mathematical skills, and computational skills.

ILO TS-3 Undertake a critical appraisal of their work.

ILO TS-4 Manage workloads and time effectively.

As mentioned in the previous section in reference to the constructive alignment approach described by Biggs and Tang (2007), it is critical to design teaching/learning methods that engage students in activities that link directly to achieving the ILOs, and to develop methods for assessing how well the ILOs have been achieved. The next section describes how we have designed the course according to this.

THE BPS COURSE

This current section summarizes the BPS learning cycle we have developed based upon the ILOs presented in the previous section. It then describes the teaching/learning and assessment methods we have devised for our course.

BPS learning cycle

Inspired by Experiential Learning Theory introduced earlier, we have proposed a continuous learning cycle for BPS that includes Kolb's four stages of learning (Beausoleil-Morrison and Hopfe, 2015). This is illustrated in Figure 2. In this earlier paper we argued for the recursive application of this cycle in order to develop the necessary knowledge and skills to effectively apply BPS tools.

Although the cycle can begin with any mode, all modes are equally important and must be followed in a sequence in order to produce the desired learning outcomes. The four modes are briefly described as follows:

- *Concrete experience* involves learning how to scrutinize results and diagnose issues with BPS representations of buildings. This can happen through direct feedback and through the examination and autopsy of simulation results in a group setting. The objective is to impact a certain degree of skepticism in BPS tools and to encourage greater scrutiny of simulation predictions.

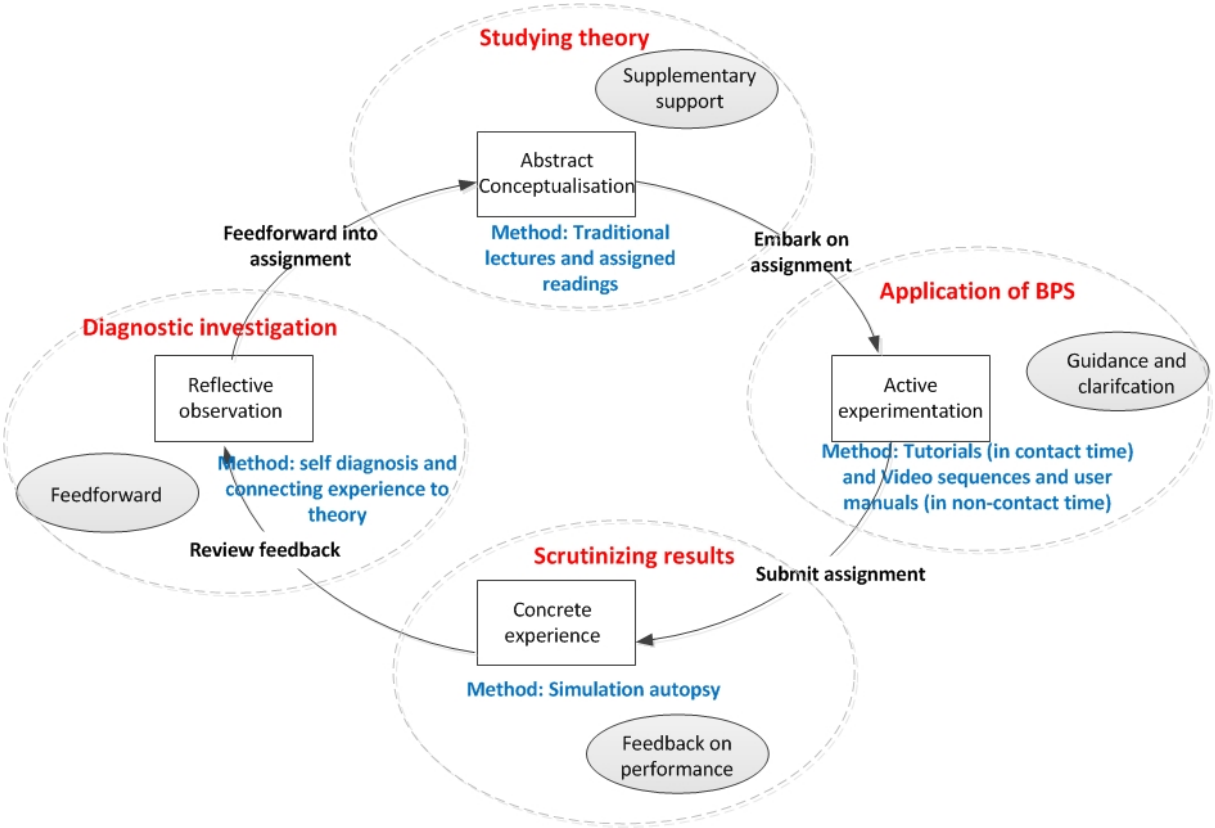

Figure 2: The BPS continuous learning cycle (from Beausoleil-Morrison and Hopfe, 2015)

- *Reflective observation* involves self-diagnosis and reviewing and connecting experience to theory. Through these activities students strengthen their understanding of models and simulation methods.
- *Abstract conceptualization* involves the study of models and simulation methods through lectures, assigned readings, and group discussions. The objective is for the students to understand the theoretical implications of their choices of BPS tools or alternate modelling methods, and to appreciate the uncertainties associated with BPS analyses so that they can contextualize their findings.
- *Active experimentation* involves the application of BPS tools in simulation exercises. This allows students to explore BPS tools and alternate modelling methods to reinforce the theoretical studies.

Beausoleil-Morrison and Hopfe (2015) provide a more detailed description and examples of these four modes of learning using an assignment based upon ASHRAE Standard 140 (ANSI/ASHRAE, 2007).

Teaching methods and course organization

Within the existing learning cycle, we try to provide a balance between concrete information (delivered via lectures) and the application of BPS. Following an initial guidance section, where the students are provided with training on the operation of BPS tools, the students are given structured exercises. These exercises provide the students with a direct encounter with the material being studied, forming the active experimentation stage of the learning cycle.

Each exercise is performed in parallel to the lectures and assigned readings according to a schedule. For example, if taught in semester format, a lecture on energy and mass transfer within buildings is given in week 3. The assigned readings associated with this topic are discussed in week 4. Students submit the results of the simulation exercise on energy and mass transfer within buildings a day prior to the lecture in week 5, during which the results are collectively analyzed.

In conducting the structured exercises, the students are left very much alone to complete the practical work and submit it on an individual basis. Any further interaction between the lecturer and students is instigated through student questions in designated open office hours or in scheduled workshops. The format of the task is reflected in the learning cycle, in terms of the experience and reflection stages.

The discussion of all results provides the opportunity for reflection on the experience by the students and then allows learning from the experience to take place via applying the known theory to the assignment. This process is part of the concrete experience and in form of a simulation autopsy helps in scrutinizing the results.

Assessment

The continuous assessment is based on pro-active participation in scheduled activities, lectures, exercises and practical work, and successful completion of a series of assignments. Regular learning schedules, teamwork discussions, and presentations also form part of the assessment. Feedback on students performance is provided after around three weeks time–however, the students have the possibility to ask questions related to the assignment in open office hours and during scheduled class times. We have prepared 15 simulation exercises for the current iteration of the course addressing 15 out of the course's 20 topics. We have designed these in relevance to the ILOs.

Problematic

As illustrated in Figure 2 we use lectures, tutorials, and tool user manuals as methods for conveying the material. This is supported by online learning management systems, where we post such things as video screen captures of the simulation autopsies and tutorials. It must be noted, however, that it is challenging to address the issue of what the students should do with the information and how to apply it when leaving the lecture theatre. For example, in the context of BPS, there are a few online tutorials, help menus, video sequences etc available that solely demonstrate how to use a tool. The students mostly have some idea what the tool is capable of. However, no help menu, or online tutorial describes what has actually gone wrong when, for example, the space heating demand falls outside of the common boundaries, nor indeed what actually are the boundaries? How do they diagnose what the problem is and what the solutions are? How do they know in the first place that there is even a problem and that they should not take every result on face value?

These sequences of actions, procedures, etc are important to teach as well (as discussed in the introduction on factual knowledge versus the procedure of acquiring the knowledge), if the theoretical teaching is to have any grounding in reality. This aspect is not at all easy, since it is predicated upon a depth of knowledge and practical experience, which the students might have not yet acquired. It is essential therefore to understand and parameterise what the student is supposed to perform and the target outcomes of the course in the future. Determining not only the procedures to be taught in the course, but also the knowledge the students need in order to perform the procedure correctly, and meaningfully.

To help illustrate our methods, two examples from the course curriculum are shown in the following sections to reiterate how our assignments are used to reinforce the link between the factual and procedural knowledge.

INTERNAL SURFACE ENERGY BALANCE

During the introductory phase of the course, students are provided an overview of the BPS domain, its history and current situation, and introduced to tools. The active experimentation during this phase of the course is for the students to develop BPS representations of a simple one-zone building with two windows that is located in London, UK. This is referred to as the *base case* and is illustrated in Figure 3.

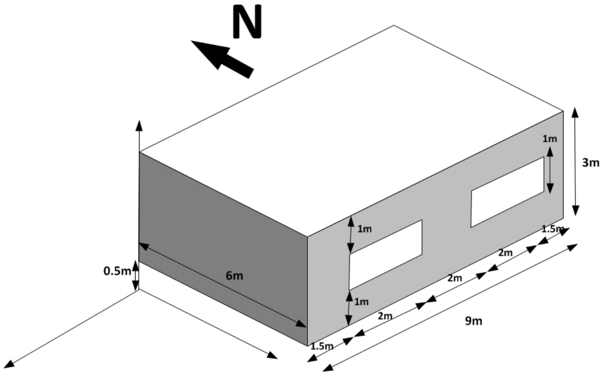

Figure 3: Base case

The creation of the BPS representation of the *base case* is supported with in-class tutorials on operating the tools, along with video sequences and tool manuals. The objective of this first simulation exercise is for students to develop a basic familiarity with the operation of the chosen BPS tools, and to develop an appreciation of the types of data required to describe geometry, wall constructions, windows, internal gains, etc. Through this work students also develop familiarity with extracting simulation predictions, such as integrated space heating loads, peak heating loads, and zone air temperatures.

The course curriculum consists a number of topics–each exploring a specific heat or mass transfer process–that collectively address the ILOs outlined earlier. This section explains the methods used to support the teaching of how energy balances are formed at internal building surfaces. Lectures (^{1}in Figure 4) are used to illustrate how energy balances can be formed for control volumes (of finite or of infinite thickness, since both approaches are used in contemporary BPS tools), and to discuss the terms that are typically included in these energy balances. This includes illustrating the devel-

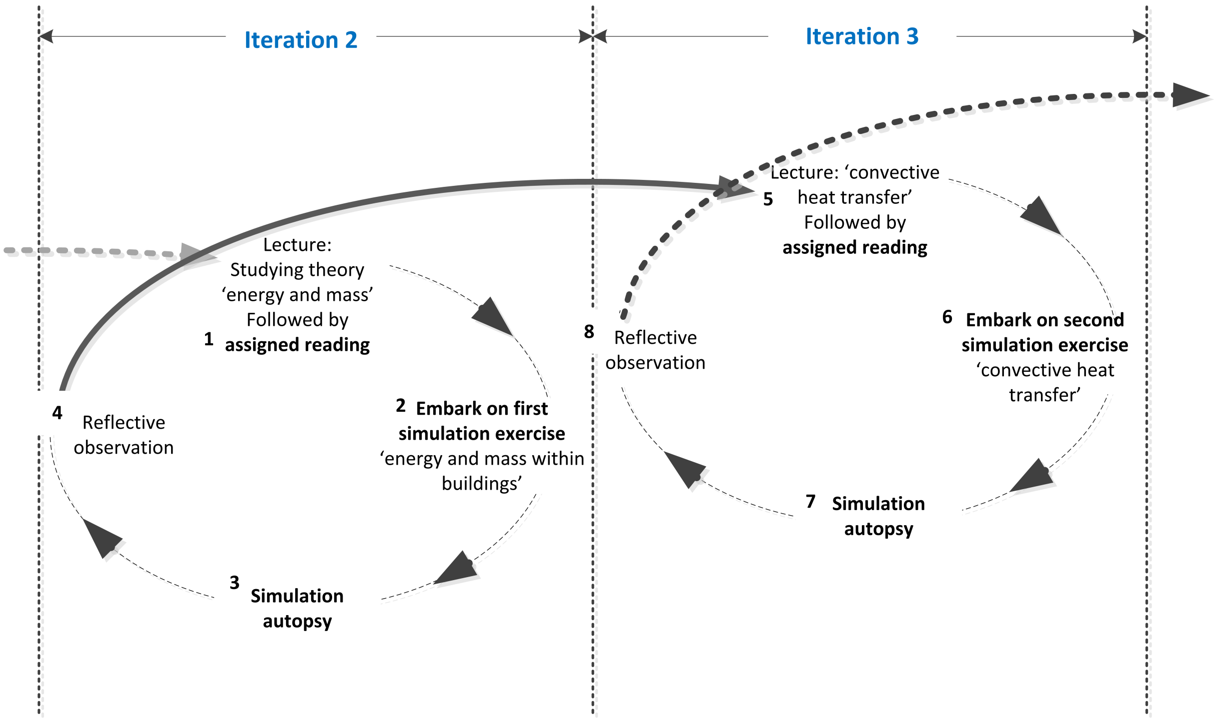

Figure 4: An example of two iterations of our continuous learning cycle; each iteration can form part of a week (in case of a semester-long course) or half a day workshop (if taught as a block-week module). In terms of the numbers $^{1-4}$ *refer to the "internal surface energy balance" section and for* $^{5-8}$ *refer to the "convective heat transfer" section.*

opment of these energy balances in equation form, although at this stage, the methods used to resolve the individual heat transfer paths appearing in the equations (e.g. convection to the surrounding air, solar absorption) are not treated. This provides the students with a theoretical understanding of the methods.

Assigned readings

Students are then assigned readings from the literature to support further learning ([1] in Figure 4). This is guided by questions we posed to help focus their study and to relate the readings to the lecture material. Typically these questions are discussed as a group in a subsequent lecture to further reinforce the material.

The following is an example:

> *In the early days of BPS it was not possible to form and solve detailed energy balances on each surface one a time-step basis due to computational limitations. In 1967, Stephenson and Mitalas (1967) introduced the* response factor *(also known as* weighting factor*) methods for subdividing the problem domain to minimize the computational burden. Most of the earlier generations of BPS tools–some of which are still in use today–were based upon these methods. Report the principle assumptions that must be invoked to make use of this technique. What are the potential implications of these assumptions on the accuracy of simulation predictions?*

The purpose of the above reading is to make students aware of some significant development in the early days of the field, and to understand the motivation for some of the simplifications that were necessary.

Another assigned reading is used to help students develop the ability to understand the strengths and limitations of competing methods, with the goal that they will develop abilities for selecting tools appropriate for the tasks at hand:

> *Most modern BPS tools employ some variant of the* heat balance *method using equations like those presented in the lectures. Sowell and Hittle (1995) provided an historical perspective on the contrast between the weighting factor and heat balance methods for resolving energy balances on zone air volumes and internal surfaces. Based upon this reading, what are the advantages of the heat balance method? Make reference to specific equations presented in lectures in formulating your response.*

Simulation exercise

Building upon the lectures and assigned readings, students perform simulation exercises to reinforce the theory (^{2} in Figure 4). For example, building upon their previous work creating the BPS representations of the *base case*, students are provided the following instruction aimed at furthering their understanding of internal surface energy balances:

> *Extract the simulation predictions for the* base case *for February 21 and create a temperature-versus-time graph for this day. Plot the zone air temperature and the temperature of the internal surface of the north wall on this graph. Superimpose on this graph the temperature of the internal surface of the floor. Why do the temperatures of these internal surfaces vary over the course of the day? How will the magnitude and direction of the convective heat transfer between the zone air and the north wall will vary over the day.*

February 21 was chosen for this exercise because it is a relatively cool day with high solar irradiance, conditions that result in internal surface energy balances in which most modes of heat transfer are significant.

Figure 5 is an example result for this exercise (^{3} in Figure 4). To construct such a figure, students are required to learn–either through self-exploration or through consulting user manuals–the methods required to extract internal surface temperature predictions. (Through the *base case* they already learnt how to extract zone air temperature predictions.)

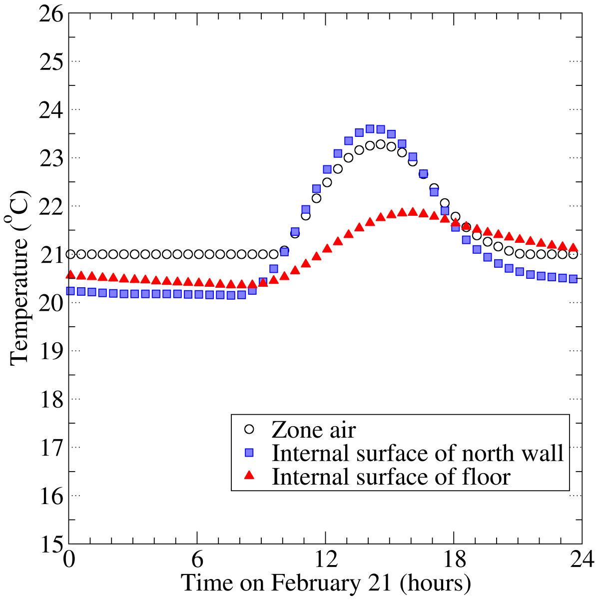

Figure 5: Example results from the first part of the simulation exercise on internal surface energy balances

The first question associated with this exercise is designed to motivate students to examine the form of the internal surface energy balance presented during the lecture and to think about the terms representing the individual heat transfer paths. Although the details of these individual terms are not yet apparent, the student should be able to deduce that the term representing the absorbed solar irradiance is the likely causing the temperatures of the internal surfaces of the north wall and the floor to increase after sunrise, and then to decrease as darkness returns. The goal here is to give the student an appreciation of the factors that must be considered in forming and solving these energy balances (^{4} in Figure 4) .

The second question motivates students to reflect upon the convective heat transfer term appearing in the internal surface energy balance. Although the functional form of this term has not yet been presented, the students should deduce that heat will be transferred from the zone air to the north wall through convection during the first few hours of the day because the air is warmer than the wall surface. And that the direction of heat transfer will reverse from about 11h to 16h, when the absorbed solar radiation has caused the temperature of the internal surface of the north wall to rise above that of the air (^{4} in Figure 4).

The next step of the simulation exercise builds upon this (^{2} in Figure 4):

> *Create a second graph for plotting the rate of heat transfer (W) versus time to the internal surface of the north wall. Extract the simulation predictions for the following heat fluxes and plot these on the graph:*
>
> - *The solar radiation absorbed by the surface.*
> - *The convection from the zone air to the surface.*
> - *The net longwave radiation exchange from the other internal surfaces in the zone to the north wall.*
>
> *Observe the magnitude of the heat transfer rates and their variation over the day. How does the previous graph (Figure 5) help explain the variation of the net longwave radiation heat transfer over the day? How does the convective heat transfer rate compare with the explanation you provided in the previous step?*

Figure 6 is an example result for this exercise (^{3} in Figure 4). Once again, through constructing such a figure students gain further skills at extracting intermediate simulation predictions.

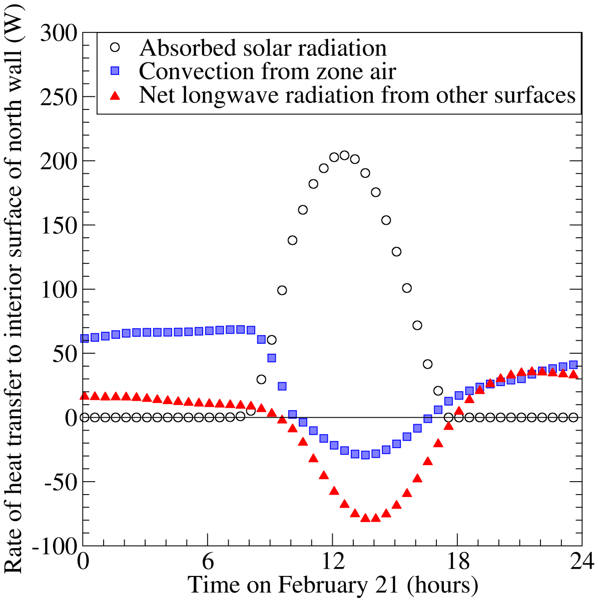

Figure 6: Example results from the second part of the simulation exercise on internal surface energy balances

One purpose of this exercise is to make students aware of the relative significance of the individual terms appearing in the internal surface energy balance. Constructing a graph such as Figure 6 should make them realize that all three terms considered here are equally important, and provide motivation for future course topics that examine the models that are used for resolving these individual heat transfer paths (^{4} in Figure 4).

The question regarding longwave radiation is aimed at helping students make the connection that the solution of the energy balance for one surface (the floor in this case) will affect the solution of the energy balance for other surfaces (the north wall in this case).

Whether the student's prediction of the convective heat transfer from the previous step is confirmed or not by this step, the aim is for the student to develop an introductory understanding of how this mode of heat transfer is modelled, and to provide motivation for studying this in detail in a subsequent iteration through the learning cycle.

These exercises should make students aware that uncertainties introduced in resolving any individual heat transfer path for any of the surfaces in a zone will impact the energy balances and the resulting temperature and heat transfer predictions and motivate them for further study.

Students conduct these exercises in isolation and submit their results to the course instructor. These predictions are collectively examined during the next class when methods are demonstrated for diagnosing causes of disagreement between students and BPS tools (^{3} in Figure 4). Students are then invited to further diagnose and revise their models using these techniques (^{4} in Figure 4) before moving onto the next topic in the course (Iteration 2 in Figure 4). As space limitations prevent a detailed explanation of these aspects of the learning cycle, the interested reader is referred to Beausoleil-Morrison and Hopfe (2015) for some details.

CONVECTIVE HEAT TRANSFER AT INTERNAL SURFACES

The previous section discussed the four learning modes used to teach internal surface energy balances. Following this, the next iteration of the learning cycle is commenced for the topic of convection heat transfer at internal surfaces, as illustrated in Figure 4.

The lecture material builds upon the previous iteration through the learning cycle by illustrating the equations used to resolve the surface convection term of the internal surface energy balance, and by explaining the methods that are used for calculating convection coefficients.

Assigned readings

One of the assigned readings (^{5} in Figure 4) employed here encourages the students to develop an understanding of the current state-of-art:

> *Peeters et al. (2011) summarize the methods that are available for calculating convection coefficients for internal building surfaces. Based on this, what are the strengths and limitations of the available methods for establishing convection coefficients for natural convection and forced flow situations? What are the inherent limitations of the well-mixed assumption and Newton's Law of Cooling approaches that are universally employed by BPS tools?*

The group discussion following this assigned reading is aimed at identifying the major sources of uncertainty in selecting equations for calculating convection coefficients for prevailing flow regimes and the associated uncertainties. This is related to the simulation exercise from the previous iteration of the cycle (^{2} in Figure 4) in which students realized that internal surface convection is a significant heat transfer path.

Simulation exercise

Simulation exercises (^{6} in Figure 4) are then used to guide the students through a detailed exploration of the methods used to resolve this heat transfer path by their chosen tool:

> *Time-invariant convection coefficients were prescribed for all internal surfaces for the* base case. *Now perform a second simulation with a different treatment for internal surface convection. Rather*

> *than using the* base case*'s prescribed values, allow your BPS tool to determine the convection coefficients for each internal surface using its default modelling approach. What impact does this have upon the annual space heating load? What is the default approach applied by the BPS tool you are using? How does this explain the differences between the two simulation predictions?*

This exercise requires the students to explore the documentation for their BPS tool to understand its options for calculating internal convection coefficients, and to determine its default modelling approach. Although results will vary from one tool to the next ([7] in Figure 4), through this exercise students will find that this change will have an impact of 10% or more on the annual space heating load. This is a revealing result because most BPS practitioners (experienced as well as novice) rely upon their tool's default treatment, often without understanding the inherent assumptions.

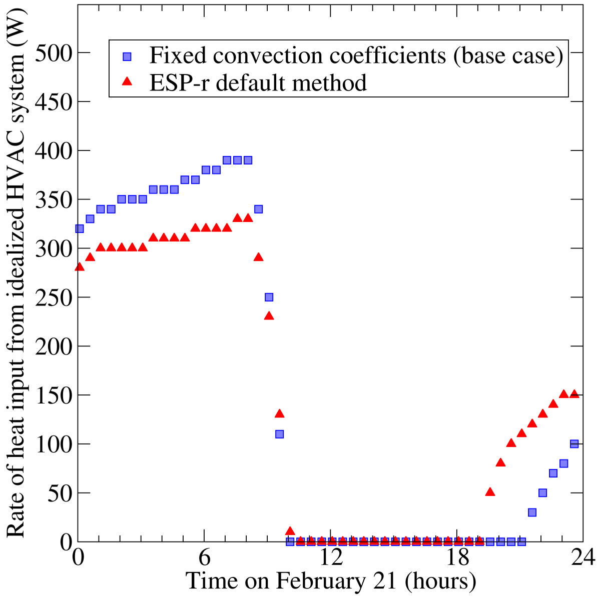

Figure 7: Example results from the second part of the simulation exercise on internal surface convection

The next step in the simulation exercise ([6] in Figure 4) has the students explore in greater depth the choice of modelling approach upon temporal results:

> *Extract the results for February 21 and create a graph that plots the rate of heat input from the idealized HVAC system versus time. How does the choice of method for treating convective heat transfer at internal surfaces impact the magnitude and timing of heat injection required by the HVAC system?*

Figure 7 is an example result for this exercise. Through this exercise students will learn that this choice of modelling method not only impacts the magnitude of required heat injection (as was seen in the last step), but also the timing of required heat injections ([8] in Figure 4). An inspection of Figure 7 reveals that in the evening of this day, the heating system is required to switch on at 21h in the *base case*, whereas when the tool's default approach was invoked the heating system was predicted to switch on at 19h, two hours earlier.

As described in the previous section, the students results from these exercises are collectively examined during the next class using a simulation autopsy and the students build upon this to refine their BPS representations. The cycle is then repeated for the next and subsequent topics to fully explore each heat and mass transfer process relevant to buildings.

STUDENT FEEDBACK

The previous sections presented two examples of the simulation exercises we have created. The creation of these exercises has been an iterative process that has benefited from feedback from students, which is treated in the current section.

Student groups

Two groups of students at Loughborough University have trialed our simulation exercises. The first was a group of 24 students studying a module on *Advanced Thermal Modelling* of the MSc programme on *Low Carbon Building Design and Modelling*. The second was a group of 5 PhD students that formed a focus group assembled for the purposes of evaluating these teaching methods. Both groups of students conducted the three exercises treated in the previous two sections: the *base case*, the internal surface energy balance, and convective heat transfer at internal surfaces.

Most of the MSc students had no prior experience with BPS tools. All PhD students were experience users, but were asked to use an unfamiliar tool to conduct the exercises. Our goal here was to learn how students with varying degrees of experience would deal with the exercises.

We have designed the course to be tool-independent. As detailed in this paper's ILO section, one of our goals is for students to develop an understanding of the underlying physical models that are implemented into BPS tools for treating the significant heat and mass transfer processes; it is not our aim to train students to become experts at operating any particular tool. Consequently, to ensure that the exercises are broadly applicable we conducted these trials using a range of BPS tools. The

MSc students used IES-ve, whereas the PhD students used EnergyPlus, DesignBuilder, IES-ve, TRNSYS, and OpenStudio.

Procedure and type of feedback

Students were provided the written description of the exercises. This was supplemented with a verbal description during which we explained the objectives of each exercise. The students were asked to record the length of time required to conduct each exercise; our goal here was to ensure that the overall course content would not exceed the requirements of a block-week module or a semester-long course.

We gathered two different types of feedback from the students:

1. In-class feedback immediately after the module's workshop (MSc students)
2. Group evaluation after the focus group (PhD students)

The first type is a common method of gathering feedback from students. It takes around 15 minutes during class to have them anonymously complete a feedback form. We posed the following two questions to the MSc students using a free-response format:

- What have you specifically learnt from undertaking these exercises?
- What would you recommend to help further improve these assignments?

In the second type of feedback gathering we tried to understand issues with each of the exercises in particular. Consequently, we added a quantitative rating with questions referring to each part of each exercise. Specifically, we asked the PhD students to rank each in terms of clarity, difficulty, and usefulness, and to record time requirements. Finally, we asked the group of PhD students to form a consensus response through discussion with respect to the following three questions:

- Quickly identify what your group sees as the primary learning objectives of the course?
- What aspects of this course would you identify as most helpful to your learning?
- What modifications to this course do you believe would help you to learn more effectively?

In-class feedback from MSc students

All students agreed that it was an enjoyable exercise and that they experienced a steep learning curve.

If we begin by asking the question: *what they have specifically learnt from undertaking the assignments?* we note that much of the feedback addressed the *base case* exercise. For example, students commented how[1]:

- They have learnt to "input building materials data and assign it to a building".
- They have learnt how to "set up a building model in BPS" and how to "modify construction types" and how "to analyse the energy consumption in a house".
- The assignment has "reinforced" their "understanding of building wall constructions and glazing".
- Their critique included comments such as "the tool seemed limited in changing some aspects/parameters" (e.g. could not find the specific glazing brand in the tool's database).

Many comments were related to the output and the data that we asked them to plot in the results, for example:

- They have learnt "how to manipulate extracted data" and how to "generate simulation data on specific building elements".
- They are "now able to generate and analyse differences of temperature from different surfaces".

Some of the feedback referred to the phase of scrutinizing the results and investigating what the source of potential errors could be and some stated that the assignments made them aware of "ensuring that all parameters are correct".

With the second question: *What they would recommend to help further improve the exercises?* it was good to see that all students experienced the assignments as an enjoyable task. They often addressed the need for additional support by means of:

- "The introduction of an interactive tutorial".
- "Video guides to show the use of a particular tool".
- "More handouts that show the assignment in greater detail and through the inclusion of more in-between steps".
- "More guidance is needed on where tool settings can be changed".

Some answers in particular addressed the clarity of how the assignment was presented and how the text was phrased and noted that in some aspects (such as the window description) more details were needed.

Quantitative rankings by PhD students

We asked the PhD students to rank each of the three simulation exercises in terms of clarity, difficulty, and usefulness, and to record time requirements. Their evaluations of clarity, difficulty, and usefulness are illustrated in Figure 8.

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[1] Quotations taken directly from student feedback forms.

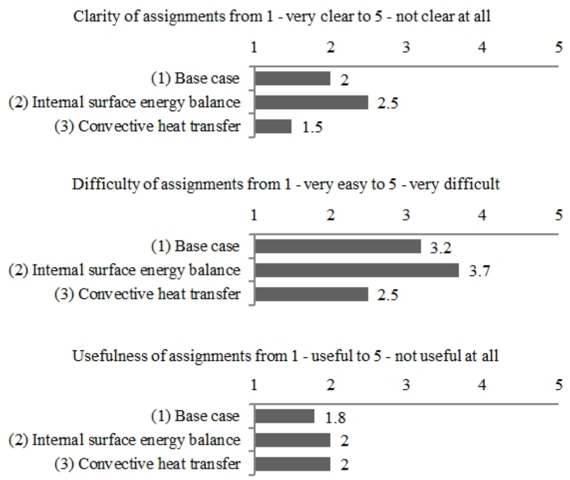

Figure 8: Averaged results of the quantitative feedback on clarity, difficulty, and usefulness of the assignments obtained from the focus group.

Group evaluation by PhD students

We did not inform the group of PhD students of the course ILOs described earlier in this paper. To evaluate whether our simulation exercises matched well to our ILOs, we asked the group of PhD students to quickly identify what they saw as the primary learning objective of the assignments. They concluded the following:

1. Understanding the building physics employed by a specific software tool.
2. Understanding the scale of mistakes when using software and to get a feeling for what is a viable input, and what is out of range.
3. Understanding the consequences of different input data and the sensitivity this has on the output.
4. Realize how to translate model specification into a building simulation tool.

The second question challenged the group to define what aspects of the exercises they would identify as most helpful to their learning. Their collective answer was that:

- They liked that each section focussed on one particular aspect rather than treating the building and all the physical principles as a whole. That allowed them to achieve a thorough understanding of the physics involved.
- They also enjoyed that each aspect was treated in separation; and this made them appreciate the magnitude of compounding factors.
- Overall, they reported that the assignments were well-structured and clear.

The third and final question asked them to suggest possible modifications to these assignments. They believe the following would help them to learn more effectively:

- Shorter rather than longer questions would help. If long questions are used, the keywords should be highlighted as otherwise due to the complexity of the text the fun of doing the assignment could be ruined.
- By using a simple (single zone) *base case*, they felt that the *real world* aspect was missing and the introduction of a real building would help. They also appreciated that it was only a simple case study to begin with and was used to isolate some of the concepts. They stated that even if a real case is used, it should be simple too, e.g. maximum a two-storey building.
- They remarked that, crucial aspects in the delivery of the course centred on the interim steps (which involved discussing and comparing results) and that time should not be lost in spending several hours on software installation issues (which occurred in one case).

All agreed that it was an enjoyable experience, and one that motivated them to further exploration. In contrast, one person felt frustrated in places due to issues with the software and the installation.

Reflection

In the piloted assignments we have utilised a number of different teaching styles. Firstly, teacher-centred– whereby we transmit knowledge to the students in the form of a formal introduction/presentation. Secondly, we move towards a student-centred approach via the simulation autopsy/group discussion.

However, although we moderate and focus the discussion it is important not to take control when the discussion becomes challenging. This is when the students are in charge of their own learning and when they put into practice the knowledge they have gained in the theoretical session.

Timing

Even though timing was one of the aspects mentioned in the feedback/ criticism, the overall amount of time the students spent in conducting the assignments was within the limits we set out initially. Regardless of their experience, i.e. in the MSc module's workshop and in the PhD focus group, the students needed 80-140 minutes for the *base case*. The energy and mass transfer exercise took 60-90 minutes, while the convective heat transfer exercise took 40-60 minutes.

What went well?

The students were attentive in the MSc module's workshop and during the introduction session and worked effectively. The timing of the session (introduction, conducting assignments, discussion of results) worked well.

The students felt comfortable in addressing their problems, doing the simulation autopsy, and providing feedback (in form of the questionnaires or verbally). The majority of students actively participated in the small group work and the larger group discussions. As a result, their understanding using the example and discussion section helped them in creating their models.

What did not work well?

In the PhD focus group, the students commented that too many types of software were used as well as experiencing software problems during installation. Assignments were not perceived as clear and concise in some cases and from their response we felt that the students struggled due to the complexity of the questions rather than the difficulty of executing the instructions. More clarity was needed in the descriptions of the *base case*, e.g. the material section was generating more questions than it answered.

What will we do differently?

Although we gave an introduction to the topic we should also cover the learning objectives at the beginning and revisit them at the end. We also need to provide a summary at the end of the session to draw together the material learnt in this round of the learning cycle and put down in writing how it ties in to the remainder of the course.

Since conducting these trials, the clarity of some of the assignments has been revised and further detail has been added to some of the sections (e.g. window properties). The material presented in the two preceding sections is, in fact, the current iteration that has been improved by the student feedback described here.

CONCLUDING REMARKS

Based on the interconnected learning cycle, the first two assignments of a course curriculum for students on how to simultaneously reinforce their theoretical and applied understanding are introduced and tested with two different student groups. In two feedback sessions, we experienced a good correspondence between the group's assessment and our ILOs: When asking them to quickly identify what they saw as the primary learning objectives, their answers corresponded well with our ILOs for knowledge and understanding as well as practical skills. The students experienced greater awareness of the consequences of their decisions and a more critical understanding of the limitations inherent in the process of numerically modelling physical phenomena. One of the learning outcomes, i.e. to find out that the user is the biggest source of uncertainty, was not mentioned despite the fact that they underwent a number of different design iterations in the simulation autopsy.

In future papers we will present more detailed feedback from the Carleton University students who are currently taking the course.

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