Facilitating Self-Regulated Learning in Mechanical Engineering Education: An Educational Design Research Study

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Abstract

This study investigates self-regulated learning challenges among students in Heat Transfer, a blended learning course offered at the University of Twente, Vrije Universiteit Amsterdam, and RWTH Aachen University. Despite its flexible course design, students consistently struggle with low engagement, poor exam performance, and a lack of deep conceptual understanding. A design-based research approach was employed to investigate the root causes of these challenges through Zimmerman's (2008) cyclical model of self-regulated learning. The results revealed three major challenges: (1) a partial implementation of the flipped classroom model that reduces effectiveness due to weak integration between online and in-person activities, (2) a bonus point system that promotes performance-driven behaviours over deep learning, and (3) a course design that assumes overly high levels of self-regulated learning without providing sufficient scaffolding or feedback mechanisms. To address these challenges, process worksheets were constructed to scaffold the development of complex problem-solving skills by supporting students' planning, monitoring, and reflection activities during their study hours.

Keywords: Blended learning environments, self-regulated learning, metacognitive calibration, flipped classroom, mechanical engineering education

Initial orientation

Problem statement

Since the COVID-19 pandemic, students have requested more freedom in their learning and meaningful class interactions (Turner et al., 2023). The annual Heat Transfer course offered at the University of Twente, the Vrije Universiteit Amsterdam, and RWTH Aachen University is an example of a course that was designed to accommodate this. During the pandemic, the course transitioned to a new teaching concept based on a blended learning model called "flipped classroom". In this approach, students are expected to self-responsibly engage with online course content before class so that in-class time can be spent on hands-on activities and group discussions (Ashraf et al., 2021). For the Heat Transfer students, online learning is facilitated through the provision of self-study learning paths with relevant content on the self-developed platform HeatQuiz (www.heatquiz.app). The offline component of the course comprises physical lectures where attendance is encouraged but optional.

Unfortunately, despite the increased freedom, course results have shown that many students struggle to achieve positive learning outcomes and pass the course successfully. This is often paired with poor motivation, ineffective time management, and a reluctance to attend physical classes among students (Rohlfs et al., 2023). Blended learning environments (BLE) have been associated with similar student challenges (Nikolopoulou & Zacharis, 2023; Muhria et al., 2023). The course's stakeholders hypothesize that this is rooted in students' lack of self-regulated learning (SRL) skills, such as monitoring and self-assessment (Panadero, 2017). This led to the initial problem formulation: *students' underdeveloped SRL skills hinder their ability to manage their studies effectively, which contributes to counterproductive study behaviour and low exam performance*. There are currently no mechanisms in place to provide students with the necessary scaffolding to gain insight into their performance, which may prevent them from accurately assessing their learning gaps and asking for help when needed (Tober & Kapur, 2023). Thus, this study aimed to understand what SRL challenges Heat Transfer students face, what causes them, and what potential solutions there could be.

Research context

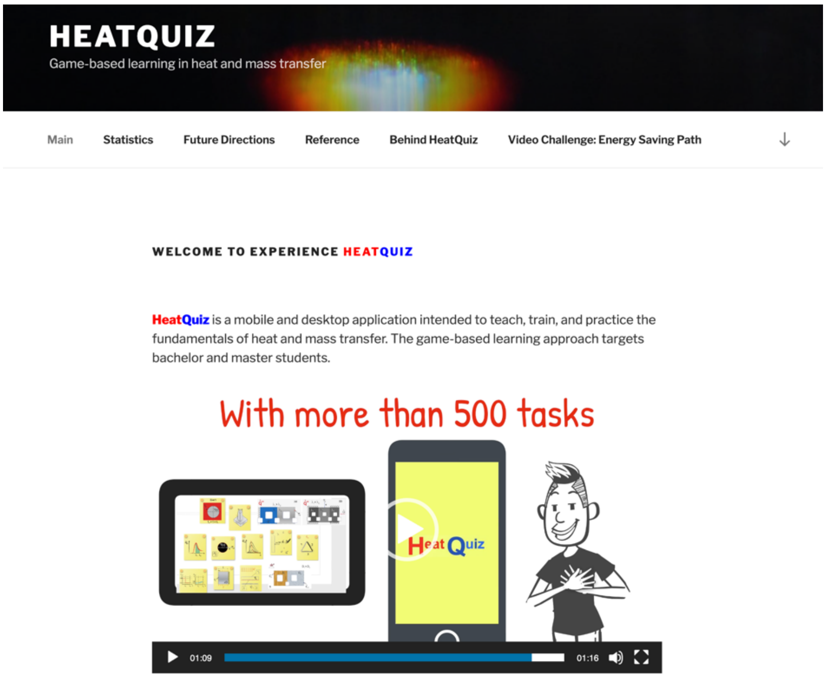
The Thermal and Fluid Engineering (TFE) department is part of the Engineering Technology (ET) faculty at the University of Twente. The department specializes in research and education related to thermodynamics, fluid mechanics, and heat and mass transport. It comprises three research groups: Engineering Fluid Dynamics, Thermal Engineering, and Multi-Scale Mechanics. It also offers a bachelor's and master's program in mechanical engineering of which the Heat Transfer course is a part.

The University of Twente, the Vrije Universiteit Amsterdam, and RWTH Aachen University organize an annual Heat Transfer course for mechanical engineering bachelor students. The course addresses heat transfer mechanisms (conduction, convection, and radiation) through practical applications. The intended learning outcome is to equip students with the ability to apply heat transfer principles in designing and analysing various engineering systems. There are 250 and 50 students enrolled in the course during its second and third-year offerings at the University of Twente and Vrije Universiteit Amsterdam, respectively. The course at RWTH Aachen University is given in the third year of study, with an annual enrolment of more than 1000 students.

The course is offered in a BLE using a flipped classroom approach. There are between six to eight in-person sessions, and they consist of three elements: (1) a summary of the relevant course material, (2) a student-driven classroom discussion, and (3) a knowledge quiz for students to earn extra credit. The sessions are supplemented by the online platform HeatQuiz (www.heatquiz.app), a software application developed by the University of Twente in collaboration with RWTH Aachen University (see Figure 1). It was designed as a self-study learning tool for students. The platform states to provide a game-based learning experience (Rohlfs et al., 2023). It does so via self-paced, linear learning paths that contain video lectures, PowerPoint slides, and quizzes.

Figure 1

HeatQuiz Website



The course also includes a summative assessment in the form of an exam to evaluate the learning outcomes. A typical exam would consist of the following elements: questions that assess the complete problem-solving process using a practical example, questions to calculate the differential equation and offer a solution for a given value, and lastly, questions to discuss results based on practical scenarios.

Stakeholders

This project is spearheaded by Prof. Dr.-Ing. Dr. rer. pol. W. Rohlfs from the TFE department at the University of Twente. The project team comprises five members. Noteworthy contributors include project partner Dr. P. Wilhelm from University College Twente (UCT), and partners from the Behavioural, Management and Social Sciences (BMS) faculty at the University of Twente. These experts bring their expertise in online learning environments, SRL, and uncertainty management to aid in developing the intervention. The initiative also involves approximately 15 teachers from the University of Twente/Vrije Universiteit Amsterdam, any associated teaching assistants (TAs), and HeatQuiz users who will directly benefit from the intervention. Furthermore, Heat Transfer students are key stakeholders, as the project aims to enhance their SRL capabilities within the course.

Theoretical framework

This section defines the main concepts that will guide this study's research and design processes. Relevant theories from the literature related to the research topic are made explicit, as will any theoretical assumptions on which this research is based.

Blended learning environments

A blended learning environment (BLE) can be defined as an instructional approach that combines in-person classroom instruction with online learning activities and resources (Güzer & Caner, 2014). The most frequently used model to apply blended learning is known as "flipped classroom" (Ashraf et al., 2021). It comprises three phases: pre-class, in-class, and an optional post-class. During the pre-class stage, students use online resources to interact with the course material, which frees up in-class time for hands-on learning activities. Durning the post-class stage, teachers evaluate students' perspectives and performance.

Several studies suggest that the flipped classroom model has a positive effect on students' metacognitive regulation (Pamuk & Alagözlü, 2024; Du et al., 2023). Others have also suggested that blended learning may be more effective in developing SRL skills than traditional instruction (Uz & Uzun, 2018; Van Laer & Elen, 2017; Xu et al., 2023). An explanation is that BLEs require students to independently engage with online materials and activities outside of class time, which pushes them to find their own knowledge gaps and inquire about them with peers and teachers more actively (Uz &Uzun, 2018; Rasheed et al., 2020; Bayyat et al., 2021).

However, BLEs may also pose challenges for students' ability to regulate their learning. To start, procrastination may occur due to the flexible nature of the online components of blended learning courses (Bayyat et al., 2021). Next, students may have difficulties using technological interfaces (Muhria et al., 2023; Rasheed et al., 2020). Moreover, BLEs require strong metacognitive skills to accurately monitor, evaluate and adapt their learning strategies (Stoten, 2019; Van Laer & Elen, 2017).

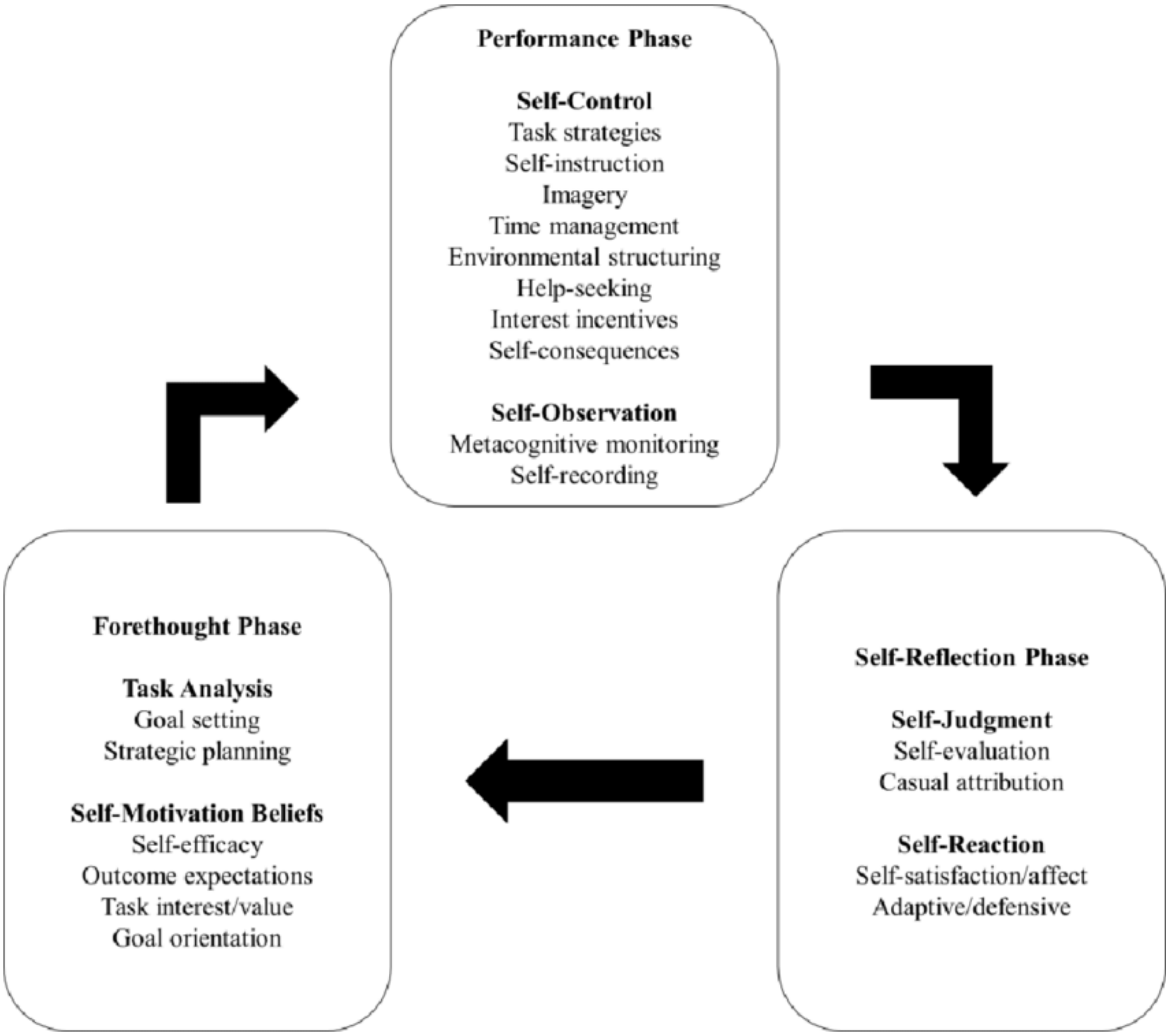
Self-regulated learning

Self-regulated learning (SRL) can be defined as the process by which learners actively control their learning behaviour by setting goals, monitoring their progress, and reflecting on their learning outcomes (Zimmerman, 2008). In BLEs, high levels of SRL have been associated with higher academic achievement (Yu, 2023; Xu et al., 2023), greater intrinsic motivation (Liu et al., 2024), and more extensive use of metacognitive strategies such as planning, monitoring, and evaluating their learning process (Eggers et al., 2021).

A widely cited model that may address the challenges a BLE is the cyclical model of Zimmerman (2008). It conceptualizes SRL as a cyclical process consisting of three main phases: forethought, performance, and self-reflection (see Figure 2). In the forethought phase, learners engage in task analysis and self-motivation processes before undertaking a learning task. In the performance phase, learners use self-control and self-observation to monitor their progress during a learning task. In the self-reflection phase, learners self-evaluate their performance against their goals and adjust learning strategies when their approach is ineffective after the learning task.

Figure 2

Cyclical Model of SRL (Zimmerman, 2008)



Various strategies can be taken to improve SRL in a flipped classroom setting. To start, pre-class assignments, frequent formative assessments, and providing choice in which resources students use to study has been associated with improved motivation and self-regulation (Onodipe et al., 2020). However, it has also been noted that factors like individual student characteristics and prior knowledge (Alkhalaf, 2023), or instructional scaffolds (Srivastava et al., 2022) may moderate their effectiveness.

Metacognitive calibration

Metacognitive calibration can be defined as the degree to which a student's subjective judgment of their performance in or understanding of a particular domain accurately reflects their actual performance or understanding level (Alexander, 2013). Students who can accurately judge their performance are deemed to possess a high calibration level, while poor levels are often characterized by over- or underconfidence in their abilities (Tobler & Kapur, 2023). Empirical research by Zhao and Ye (2020) found that higher calibration accuracy resulted in improved assignment performance, as well as students spending less time on online assignments. However, students may require instructional scaffolding through strategies such as reflective questions and self-assessment prompts to activate their metacognition in a BLE (Anthonysamy, 2021; Tuononen et al., 2023; ElSayad, 2024).

Metacognitive calibration is associated with several SRL processes. Hacker and Bol (2019) have based their analysis on the three cyclical phases of Zimmerman's model of SRL (Zimmerman, 2008): forethought, performance, and self-reflection. Related to forethought, the associated subprocess is task analysis. They state that calibration is a type of task analysis where students are asked to predict their performance on a task. In the performance phase, self-observation is most closely associated with calibration. Self-observation refers to monitoring the performance of the task. And, lastly, in self-reflection, the subprocess most closely related to calibration is self-evaluation. This provides evidence of how well the student has performed after completing a task.

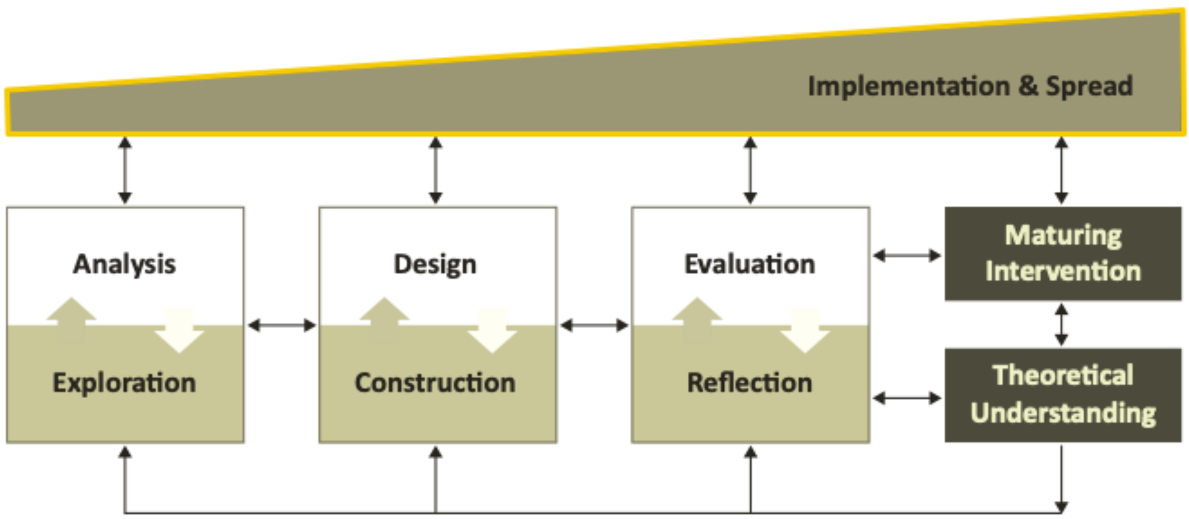
Methodology

Research design

This study employed a design-based research approach to address the challenges identified in the Heat Transfer course. The educational design research (EDR) methodology by McKenney and Reeves (2018) was chosen to structure the research process along three phases: Analysis and Exploration, Design and Construction, and Evaluation and reflection (see Figure 3). A part of a macro-cycle was completed, with only single micro-cycles for the first two phases. In the Design and Construction phase, a prototype for an intervention was constructed. Due to the project's time constraints, an evaluation plan was proposed but not executed. The following subsections describe each phase's activities and outputs in more detail.

Figure 3

A Generic Model for Conducting Educational Design Research (McKenney & Reeves, 2018)



Phase 1: Analysis and Exploration

In the Analysis stage, field-based investigation was conducted to clarify the SRL challenges of Heat Transfer students. Two methods were used: (1) document analysis to analyse course materials (Course reader, manual, HeatQuiz, and Canvas) that may identify existing SRL and scaffolding mechanisms or a lack thereof, and (2) semi-structured interviews with diverse stakeholders (students, teachers, and TAs) to explore SRL challenges from different perspectives.

In the Exploration stage, similar problems and their solutions were explored to further contextualize the issues in the Heat Transfer course. This was done through (1) a regular panel of experts from the UT, and (2) interviews with teachers from alternative, but related, course contexts. Both sources provided experiences and expertise that developed a more nuanced perspective and inspired design ideas.

The outputs included a revised problem statement, long-range goals, partial design requirements, and initial design propositions that informed the Design and Construction phase.

Phase 2: Design and Construction

In the Design stage, ideation was performed to generate potential solutions to the challenges identified in the previous phase. Solutions were brainstormed, evaluated against partial design requirements, and refined with input from the expert panel. Through a weighted ranking matrix and SRL analysis, an intervention was selected for construction. Design requirements and propositions were refined to better guide construction.

In the Construction stage, detailed design specifications from the Design stage were used to develop a functional prototype of the selected intervention. This ensured that it aligned with SRL theory and accurately addressed the identified challenges.

The outputs included finalized design requirements and propositions, detailed design specifications, and a prototype of the intervention.

Phase 3: Evaluation and Reflection

Due to time constraints, none of the stages in this phase were conducted. Instead, an evaluation plan was proposed. A beta test in the form of a tryout was suggested given to empirically test out the prototype in a real-world setting and iteratively refine it based on feedback from student, teacher and TA feedback.

Analysis & Exploration

The Analysis and Exploration phase used two qualitative research methods to clarify the SRL challenges of Heat Transfer students: document analysis and semi-interviews.

Document Analysis

Document analysis was conducted on existing course materials to gain insight into SRL mechanisms within the Heat Transfer course. The primary research question was: *"To what extent does the Heat Transfer curriculum support blended learning, SRL and metacognitive calibration?"*. This was subdivided into two secondary questions: (1) *"How is the current curriculum of the Heat Transfer course structured?"* and (2) *"To what extent do the materials support blended learning, SRL, and metacognitive calibration?"*.

Three objectives were defined to guide this document analysis. Firstly, to determine if there are existing support mechanisms that facilitate SRL processes such as planning, monitoring, and self-reflection (Zimmerman, 2008). Secondly, to evaluate if the course design provides students with opportunities to engage in metacognitive calibration processes such as task analysis, self-observation, and self-evaluation (Hacker & Bol, 2019). And lastly, to reveal learning gaps that may hinder SRL processes and metacognitive calibration (Van Laer & Elen, 2017).

Procedure

The document analysis was conducted following the qualitative content analysis framework by Mayring (2014). First, research objectives were defined to guide the analysis process and align with the overall study aims. Then, a set of inclusion criteria was formulated to ensure the selection of relevant documents. Relevant documents were systematically gathered with support from the Heat Transfer project leader. Next, coding schemes were developed iteratively. Initial categories were derived from the research objectives and theoretical framework, while additional categories emerged from preliminary reviews of the documents. Subsequently, the coding schemes were used to carefully analyse and code the documents. Finally, the coded data and emergent themes were synthesized to address the research questions.

Formulation of inclusion criteria

The following inclusion criteria were formulated to identify relevant documents: (1) directly related to the Heat Transfer course, (2) a paper or multimedia (such as a website) source, and (3) no older than two years. These criteria ensure that the documents are relevant to the research context and can shed light on the potential issues students face in the Heat Transfer course.

Selection of relevant documents

The chosen documents (n_d = 4) were the Heat Transfer course manual, the course reader, the learning management system Canvas, and the HeatQuiz platform. These resources satisfy the inclusion criteria and form a coherent picture of the course contents.

Firstly, the Heat Transfer course manual introduces the course. It describes the course's structure, learning resources, and important procedures students should be aware of at the start of the course. Secondly, the Heat Transfer course reader contains the essential content that students are required to learn during the Heat Transfer course. It includes all learning goals, explanatory materials, and exercises related to the various components of the course. Thirdly, the Canvas environment provides students with communication about the curriculum, assignments, and other important events. It includes a forum that students can use to interact with teachers and TAs. Finally, the HeatQuiz platform is an online environment that allows students to self-sufficiently navigate the course materials. It includes interactive quizzes, micro-lectures, and homework tasks, structured along a visualized learning pathway.

Development of coding scheme

Coding schemes were developed to align with the analysis objectives and are based on three theoretical models. To start, the cyclical model by Zimmerman (2008), insights from Hacker and Bol (2019), and the blended learning theory by Van Laer and Elen (2017) were utilized to develop categories based on their theoretical components. At times, they were explicitly derived from the theoretical models, in others, they were based on the researcher's interpretation. Afterward, the codes were elaborated upon through a formal definition that aligns with its theoretical foundation, as well as specifying coding rules that specify when and how to apply each code.

A two-tiered scheme was developed to separate design analysis and content analysis. The scheme for design analysis focused on educational design and how the course is built up, in theory. In this case, fragments were selected based on the presence of any educational design principle in the document. For example, if there is mention of a design element related to the code "time management", it would suffice for being coded as such.

The scheme for content analysis, on the other hand, focuses on the implicit design principles underlying the educational content and what is present in practice. Here, fragments are selected based on whether an element is present and actively stimulates learning behaviour. For example, if a "reflective prompt" is included, this would imply the presence of the SRL-related concept of "self-reflection" and that it serves to stimulate the associated learning behaviour. An overview of the design and content coding schemes can be found in Appendix A and B, respectively.

Document analysis

The analysis process for each document followed a similar structure. To start, the original purpose of the document was described. Next, the document was analysed using the appropriate coding scheme. A codebook was developed to document occurrences of codes. Subsequently, results derived from analysing the codebook were described. A summary of the codes and their occurrence per document can be seen in Table 1. The complete codebook, including codes for each document specifically, can be found in Appendix B.

Table 1

Summary of Codes Across All Documents

Theory	Category	Code	Documents				
			Course Manual	Course Reader	Canvas	HeatQuiz	Total
Self-regulated learning	**Forethought**	Task prioritization	1	1	-	1	3
		Time management	3	-	-	-	3
		Concept structuring	-	2	-	1	3
	Performance	Assessment	3	-	-	-	3
		Progress tracking	2	-	-	-	2
		Comprehension checking	-	1	1	1	3
		Active engagement	-	1	2	1	4
	Self-reflection	Error analysis	1	-	-	-	1
		Self-assessment	1	-	-	-	1
		Reflective prompts	-	-	-	-	0
Metacognitive calibration	**Judgment of learning**	Learning strategy evaluation	2	-	-	-	2
		Confidence rating	-	-	-	-	0
	Pre-task prediction	Predicting understanding	-	-	-	-	0
		Estimating difficulty	-	-	-	-	0

	Performance feedback	Immediate feedback	1	-	-	-	1
		Detailed feedback	1	-	-	-	1
	Learning strategy adjustment	Reattempting tasks	1	-	-	-	1
		Feedback integration	1	-	-	-	1
	Self-observation	Reviewing misunderstandings	-	-	-	-	0
	Post-task reflection	Calibration reflection	-	-	-	-	0
Blended learning	**Online**	Self-paced learning	2	-	-	-	1
		Online resources	1	1	1	1	4
	In-person	Instructor-led learning	1	-	-	-	1
		Collaborative learning	1	-	-	-	1
	Blended	Activity integration	1	1	1	-	3
		Cross-modality reinforcement	1	1	-	1	3

Document: Course manual

The Heat Transfer course manual provides an overview of the course components and guides students through course materials, assignments, and strategies for engaging with both online and in-class activities. As this document covers the educational design of the course, it was analysed using the coding scheme for design analysis. Text excerpts were taken whenever a coding rule fit the description. The results are found in Appendix B1.

The manual supports 11 out of the 12 codes, with only no support for the "confidence rating" code. This suggests that the educational design, at least in theory, supports SRL, metacognitive calibration, and blended learning.

Three additional observations were made. Firstly, the document presents a comprehensive overview of the educational design in a predominantly textual fashion. There is a lot of information to take in, which raises the question of to what degree students can fully comprehend its contents without additional support. Tracking of usage and perceived clarity could prove insightful.

A second observation is that the HeatQuiz platform allows students to track their progress if they provide their student number whenever using the tool. The manual states that progress will be kept track of, but not to what degree students can gain insight into it. This insight could promote SRL and metacognitive calibration through performance and progress feedback triggering reflection behaviour.

A last observation is that the manual does not strongly incorporate error analysis or self-assessment opportunities in its design. These opportunities are important for triggering reflection as a key part of metacognitive calibration, and the lack of these components might hinder students from effectively improving their learning strategies.

In sum, the course manual appears to promote SRL, metacognitive calibration, and blended learning concepts. However, it does raise the question of to what extent these concepts are sufficiently and adequately applied throughout the course, as well as to what extent students read the manual and understand it. A general learning strategy is provided. However, this may not be supported in practice.

Document: Course reader

The Heat Transfer course reader provides an overview of the complete learning content for the Heat Transfer course. It details the key concepts, principles, and practical applications of different aspects of heat transfer, such as conduction, convection, and radiation. It offers theoretical explanations alongside practical exercises to reinforce understanding.

As the reader consists of more than 300 pages, the choice was made to analyse two out of the five sections ("*Part I: Introduction to Heat Transfer*" and "*Part II: Conduction*"). The underlying assumption is that the structure and layout of the other sections remain the same. Considering that this document communicates primarily theoretical content, the coding scheme for content analysis (see Appendix A2) was used. To ensure the analysis captures both explicit and implicit information related to the coding scheme, textual, structural, and visual elements are considered. The results are described in Appendix B2.

As seen in Appendix B2, the course reader supports seven out of the 12 codes drawn from the SRL, metacognitive calibration, and blended learning theories. They are mainly SRL-related elements, like task prioritization and concept structuring, and place emphasis on forethought and performance phases of the model by Zimmerman (2008). Elements related to self-reflection, however, are missing. 100% of the blended learning-related codes, like activity integration or cross-modality reinforcement, are supported at a basic level.

Based on the document analysis, several additional observations can be made. Firstly, there are very few exercises mixed in with the content. At the end of most sections, there is a reference to a HeatQuiz quiz. There also is an exercises section per topic at the end of the book, however, it is not obvious how they would fit into the learning path when using the reader.

Secondly, there is a noticeable lack of reflective prompts to help students assess their understanding. This refers to prompts that both ask students to articulate their thoughts before engaging with new material and reflect on their performance after completing an exercise.

Thirdly, there is limited cross-modality reinforcement within the reader. The integration of QR codes for HeatQuiz quizzes, micro-lectures, and slides is there, but it might not always be evident what the best order of accessing should be. The title of the learning goals section links to the slides, but that is not visually made explicit. The QR codes are placed next to some of the text, but it is not made explicit where these will lead or when students should engage with them.

In sum, the course reader does well in supporting the initial two phases of SRL, through concept structuring, task prioritization, and encouraging active engagement. However, the design lacks sufficient elements supported by metacognitive calibration concepts to help students monitor and adjust their understanding. It also lacks sufficient integration between activities that provide cross-modality reinforcement and scaffolding in their learning process.

Document: Canvas

The Canvas website is a learning management system that helps students navigate all learning activities, materials, and communications about the Heat Transfer course. It also provides them with the ability to ask questions or mention any curriculum irregularities in the discussion forums.

The relevant sections of the Canvas website that have been analysed were (1) the homepage, (2) announcements, (3) modules, and (4) discussion pages. The homepage provides an overview of the most important communications necessary to start the course. The announcements page includes all teacher-student communication. The modules page comprises all the materials and hyperlinks to pages that provide further detail on the curriculum contents. And, lastly, the discussions page consists of various threads teachers and students have made regarding technical, organizational, and content issues. Screenshots from the Canvas website can be found in Appendix C.

In Appendix B3, the codebook of the Canvas website is shown. Given that the website mainly communicates content, the coding scheme for content analysis (see Appendix A2) was used. To ensure the analysis captures both explicit and implicit information related to the coding scheme, textual, structural, and visual elements are considered.

The Canvas website only supports four out of the 12 codes. "Active engagement" through HeatQuiz is encouraged, and the website offers a variety of online resources for self-paced learning. However, other elements related to SRL, or metacognitive calibration are entirely lacking. This may be due to the limitations of the Canvas platform or the function of it might be solely to communicate course contents.

A few other observations were made. To start, the Canvas environment does not seem to provide explicit guidance on how to best prioritize tasks and engage with the learning materials. Instead, it offers the materials and important communications, with the seemingly implicit expectation that students know what to do. This may ask a high level of SRL behaviour from students from the start, which risks leaving those who have underdeveloped SRL skills without guidance.

Next, the "discussion" section is used to clarify understanding about concepts. The pattern of communication is "student asks a question, and the TA answers" and then the communication stops. From these brief exchanges it is not apparent whether students have improved in their understanding, as there is no prompt to review their misunderstandings or reflect on their accurate comprehension.

Last, Canvas has a page that offers practice exams and solutions. The context provided is that these exercises represent the exam level, however, the page does not provide further context on what learning strategies to employ to make best use of them. Moreover, the solutions provided elaborate on the correct answer but do not incorporate prompts to reflect or review misunderstandings.

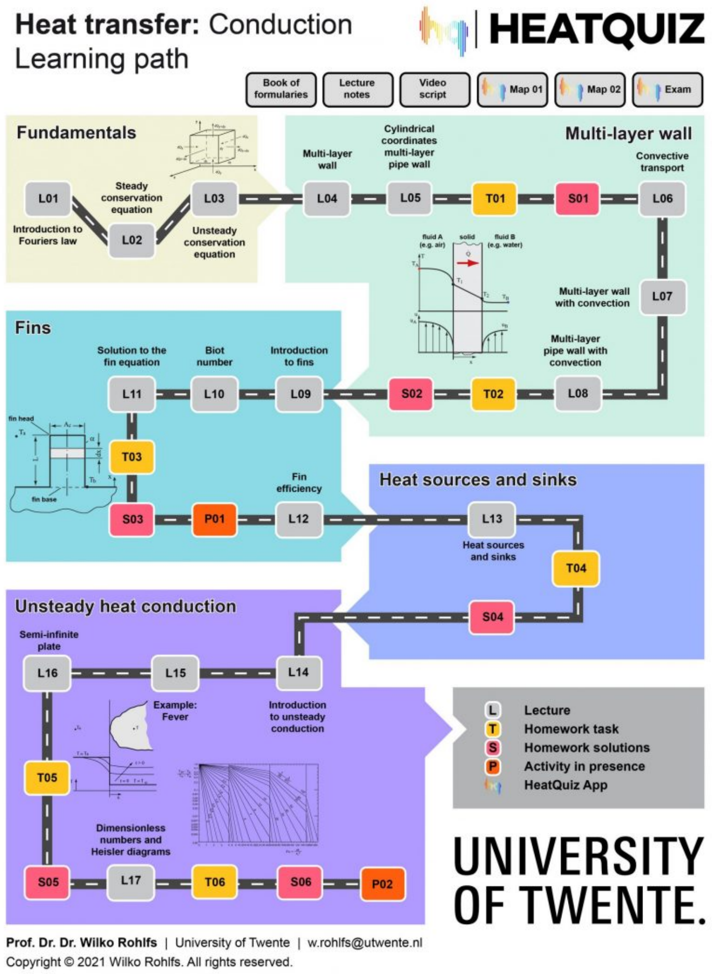
In sum, it appears that Canvas is used mainly as a centralized location for online sources. It inherently does not provide much support for the facilitation of SRL process, which may make optimal use of this challenging for those already weak in this area.

Document: HeatQuiz

HeatQuiz is an online platform designed by the University of Twente to provide students with an interactive way to learn Heat Transfer concepts. The main feature is the offering of visualized learning paths (see Figure 4) that include micro-lectures, interactive quizzes, and PowerPoint slides.

Figure 4

Conduction Learning Path on HeatQuiz



The elements of the platform that have been analysed are (1) the dashboard, (2) the visualized learning paths, (3) the popup with links to the quiz, video lecture, and slides, (4) the comprehension quizzes and answers, and (5) the time-based quizzes and answers. As the platform provides content, the coding scheme for content analysis (see Appendix A2) was used. The results from the analysis are found in Appendix B4. Additional screenshots from the HeatQuiz website can be found in Appendix D.

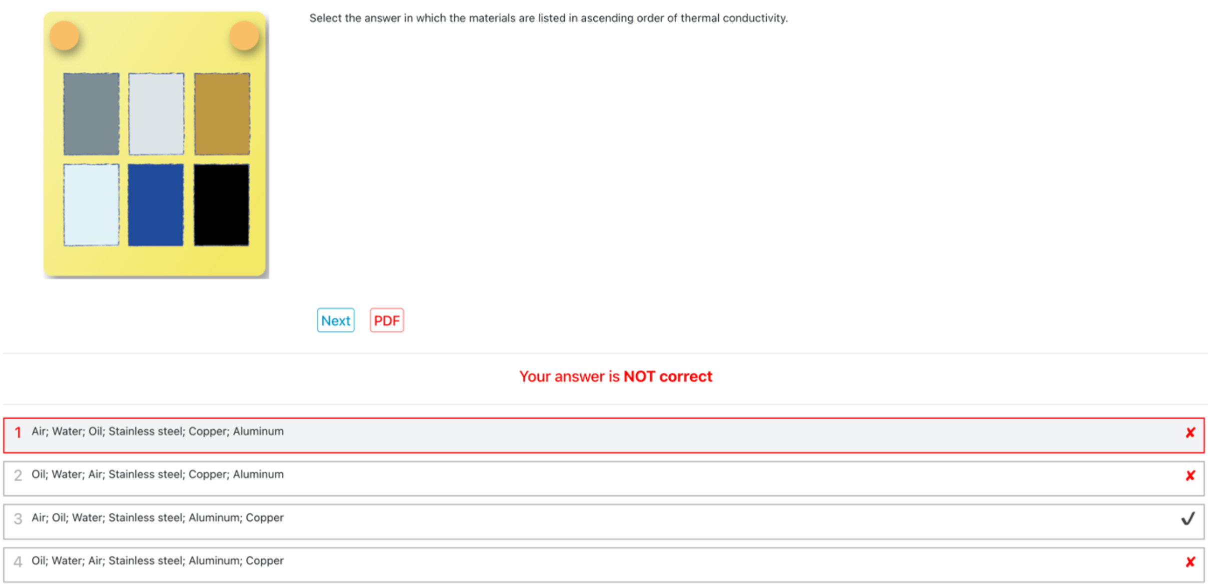
Based on the results of the document analysis, HeatQuiz supports six out of the 12 codes. These are primarily SRL-related, with a focus on the planning and self-reflection phase (Zimmerman, 2008) through codes like task prioritization and comprehension checking. Two codes are blended learning-related, with a focus mainly on online learning.

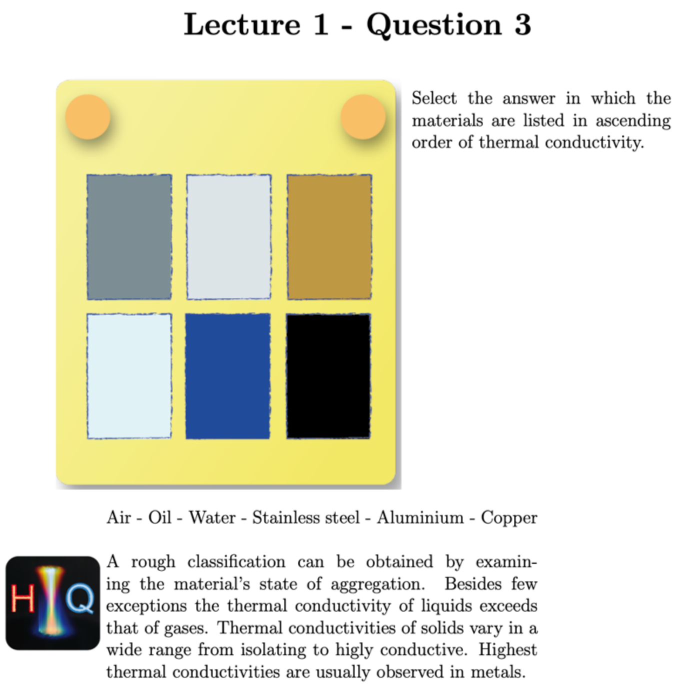
Several additional observations can be made. Firstly, the platform does not appear to incorporate features that stimulate metacognitive calibration. For example, there are no explicit prompts to estimate task difficulty, predict understanding, or reflect on the accuracy of their performance after completing tasks. While feedback for incorrect answers is provided, it does not guide students in comparing their expectations to their actual outcomes This is an important part in supporting students to adapt their learning strategy (Hacker & Bol, 2019).

Secondly, HeatQuiz offers little regarding blended learning. While digital resources like quizzes, micro-lectures, and slides are provided, there are no prompts suggesting that students refer to offline materials, like the course reader, or engage in activities that require physical participation. As a result, there is no reference to how these online activities may complement or connect with in-class activities. This raises the question of to what extent this may affect student motivation for joining offline sessions.

Figure 5

Quiz Feedback on HeatQuiz





Thirdly, the feedback given after answering quiz questions appears to focus only on explaining the correct answer (see Figure 5). It would also be useful to explain incorrect answers, as this could help students reflect on their underlying assumptions or misunderstandings of certain concepts. Especially when combined with a prompt to self-reflect, this could help students review their misunderstandings and improve their mastery of the material.

In sum, HeatQuiz promotes self-paced learning through visualized learning paths and active engagement with interactive quizzes. However, it lacks in promoting self-reflection and providing detailed feedback on performance. It also lacks any integration with other materials provided in the course, whether that's the course reader or in-person sessions.

Addressing the research questions

RQ1.1: How is the current curriculum of the Heat Transfer course structured?

The Heat Transfer course curriculum is structured around a blended learning model that combines online and in-person components. The course manual describes a flipped classroom design that encourages students to engage in online self-paced learning through the course reader and HeatQuiz, and in-person sessions through weekly tutorials that reinforce learning. The course reader provides theoretical content and exercises at the end of the book to help students study self-sufficiently. Canvas provides a centralized platform for accessing course materials and a discussion forum students can use to ask their questions to teachers and TAs directly. HeatQuiz functions as an interactive platform with visualized learning paths, video lectures, and quizzes to reinforce understanding.

RQ1.2: To what extent do the materials support blended learning, SRL, and metacognitive calibration?

After analysing the documents, it can be said that the course materials provide partial support for blended learning and SRL but none for metacognitive calibration. Concerning blended learning, the support for online, self-paced learning elements like HeatQuiz, course reader, and Canvas was strong. However, there were no documents found describing the content of the offline activities, nor any references from the documents to offline activities. Therefore, it was not possible to map out the integration between online and offline activities.

Regarding SRL, the materials focus mainly on the forethought phase. For example, HeatQuiz offers visualized learning paths, video lectures, and interactive quizzes that help students structure and prioritize their study load. This is complemented by the course reader, which linearly presents theoretical content. The performance phase, however, was less supported. For example, the exercises in the reader were put at the end, without any guidance on how to best approach them. The same could be said of the old exams on Canvas, which were uploaded including the solutions. This leads to the SRL aspect that was least supported: self-reflection. This aspect was only mentioned briefly in the manual, and in passing through the mention of learning objectives at the beginning of each chapter in the course reader. Neither the exercises nor the old exams appear to include elements that promote self-reflection.

Regarding metacognitive calibration, a similar logic as for the self-reflection aspect of the SRL could be applied. Although there are some comprehension questions in the course reader, they do not sufficiently prompt students to reflect and change their learning strategies based on their current understanding. This is exacerbated by the lack of detailed feedback mechanisms. HeatQuiz quizzes provide superficial feedback on single-step exercises but do not prompt students to reflect on the gap between their perceived and actual understanding.

Semi-Structured Interviews

Semi-structured interviews have been conducted to understand students' SRL behaviors through the perspective of various stakeholders' perceptions. The primary research question was: *"To what extent do students engage in SRL and metacognitive calibration in the Heat Transfer course?"*.

Procedure

The interviewing procedure followed several steps. To start, a request for ethical approval from the Ethics Committee of Humanities and Social Sciences of Twente University was submitted to ensure the protection of respondents' rights (see Appendix G). After receiving approval, an informed consent form with an information sheet describing the study in further detail (see Appendix H), and interview guides for each of the three different stakeholders were produced (see Appendix I) by the researcher to ensure that participants were fully informed of the topic of the research study and their data privacy rights. After the interviews, three coding schemes were developed (see Appendix J). Each scheme is tailored to a particular stakeholder: student, teacher, or TA. This was done to capture different perspectives on student challenges with SRL processes in the Heat Transfer within the context of the mentioned theoretical models.

Afterward, the researcher approached potential respondents directly via email, via the announcement page in the Canvas platform, and indirectly through members of the project team with a request to participate in an interview. An informed consent form was developed to ensure that participants were fully aware of the nature of their involvement in this research study. The informed consent form and information sheet were attached to these messages. Interested participants were followed up with via email to schedule an interview. The interviews were held online in a Microsoft Teams environment. These were audio-recorded with permission from the participants. After the interviews, the recordings were transcribed and sent to participants for verification that any personally identifiable information was removed.

Respondents

A stratified purposive sampling technique was used to “capture major variations rather than identify a common core, although the latter may also emerge in the analysis” (Palinkas et al., 2015, p. 1). Three strata have been identified to be relevant to the study: teachers, TAs, and students. Each can provide insight into the learning dynamics within the scope of the Heat Transfer course and shed light on the SRL challenges that students may face.

Teachers were sourced from the University of Twente. To qualify for the interview, teachers must have (1) at least one year of experience teaching the Heat Transfer course, (2) six months of using the HeatQuiz platform to deliver curriculum materials, and (3) taught at least one complete course from start to finish using HeatQuiz as a teaching aid to be included in the sample.

TAs were sourced from the University of Twente. To qualify for the interview, TAs must have (1) at least six months of experience supporting students in the Heat Transfer course and (2) directly interacted with students throughout the entire course to be included in the sample.

Students were sourced from the University of Twente. To qualify, students must (1) have taken the Heat Transfer course at least once, (2) have completed at least one semester in a BLE, and (3) be willing to reflect on their SRL experiences to be included in the sample.

A sample size of 11 ($n = 11$) was reached, spread among teachers ($n_t = 3$), TAs ($n_a = 2$), and students ($n_s = 6$) to gain insight into the perspectives of various stakeholders, with explicit emphasis on students' experiences. The inclusion criteria were used in the recruitment process. No distinction was made between gender, age, or experience level.

Instruments

In preparation for the interviews, interview guides were developed. After transcribing the interviews, coding schemes were developed.

Interview guides

Interview guides have been developed to address the perspectives of the three identified strata: students, teachers, and TAs (see Appendices J1, J2, and J3, respectively). The initial orientation, theoretical framework, and document analysis results informed the questions. Each guide follows the same structure, with questions adapted to better fit the context of the stratum.

Four categories of questions have been formulated: current experience, SRL, HeatQuiz, and feedback. Each guide begins with questions about current experiences, which provide a baseline understanding of the respondents' experience with the Heat Transfer course. For students, this involves their overall experience, including aspects they find challenging. For teachers and TAs, it involves how the blended learning model has influenced their roles. This may open further questions about perceived obstacles and specific examples of changes in student performance.

Questions on SRL are included to directly address the research question, based on concepts defined in the theoretical framework such as metacognitive calibration and Zimmerman's cyclical model of SRL. Students are asked how they manage their learning processes and assess their understanding of the course content. Teachers and TAs are asked about their observations of students' SRL practices, and the strategies used to help students monitor their progress. This may shed light on their study habits and the role of self-reflection in adapting learning strategies.

Questions about HeatQuiz examine its role in supporting learning and teaching. Students are asked about the features they find most useful, and uncertainties related to managing their learning process and how they address them. Teachers and TAs are asked how they incorporate and engage with the platform. This may help identify useful and problematic features.

Finally, questions about feedback solicit actionable insights for improving both the HeatQuiz platform and the Heat Transfer course. These will help during the design and construction phase.

Coding schemes

Coding schemes were developed to align with the analysis objectives and are based on three theoretical models. Firstly, the cyclical model by Zimmerman (2008) was utilized to develop codes for elements related to SRL. Next, the insights by Hacker and Bol (2019) were taken to develop codes for metacognitive calibration. Lastly, Van Laer and Elen (2017) on blended learning was used to develop codes for the blended learning components. These have been distilled into a category system that includes categories and subcategories, the latter of which will be utilized as the codes during analysis. The coding schemes were, like during document analysis, developed using the guidelines posed by Mayring (2014).

Interview analysis

The analysis process of the transcripts for each stratum (student, teacher, or TA) followed the same process. To start, each transcript was analysed using the appropriate coding scheme. A code was applied when it fit the associated coding rules. Next, results derived from analysing the codebook were described. An overview of the application of the codes per stratum can be seen in Appendix J. The complete codebook, including codes for each interview specifically, can be found in Appendix K.

Interview results

Students

A total of six students (n_s = 6) were interviewed individually. This was done in an online setting. The resulting interview transcripts were analysed with a dedicated coding scheme (see Appendix J1).

Several insights can be gained from the thematic content analysis. Firstly, five out of six students complained about the lack of guidance on how to approach the exercises in the course. They found the course materials, including the HeatQuiz platform, lacking in explaining the steps involved in handling multi-step problems. For example, one student mentioned how answer keys simply provided the final solution, without explaining the reasoning underlying the solutions. Similarly, another expressed frustration with the lack of clear steps or a "recipe" for solving problems. Also, the course reader was mentioned as something that could benefit more from including explanations on the "proper way of thinking" about heat transfer.

Secondly, four out of six students expressed a preference for a more traditional learning format. More specifically, they mentioned a desire for more in-person sessions over self-study with the reader or using HeatQuiz. For example, one student argued for the structure and accountability that in-person sessions could provide. Another imagined it to be more valuable to observe the instructor's problem-solving approach in real-time, rather than watching pre-recorded lectures. Making the in-person sessions mandatory was also mentioned so that students would have to work on assignments in groups. According to them, this could lead to valuable opportunities for interaction and knowledge sharing,

Thirdly, five out of six students voiced concerns about the bonus point system in facilitating meaningful learning. For example, two students argued that the incentive of bonus points encourages some students to prioritize memorizing answers over genuinely understanding the concepts and should, therefore, be removed from the course. In contrast, two different students noted that the bonus points motivated them to attend tutorials and engage with HeatQuiz. However, they did mention that this led to students memorizing HeatQuiz questions and answers, rather than deep understanding of the concepts.

And, lastly, all students found the HeatQuiz platform lacking in one way or another. For example, two students explicitly stated they found the platform hard to use, from a usability perspective. One felt that the quizzes in HeatQuiz lacked detailed explanations on the correct and incorrect answers after each question, as opposed to ThermalQuiz. Two different students primarily used HeatQuiz for the bonus points but did not find it particularly helpful for learning.

In sum, the major themes that emerged from the student interviews are (1) a lack of guidance in learning how to approach exercises in the course, (2) a preference for more in-person sessions, (3) a general dislike of the bonus point system due to it preventing students from engaging in meaningful learning, and (4) various perceived shortcomings of HeatQuiz.

Teachers

A total of three teachers (n_t = 3) were interviewed individually. This was also done in an online setting. The resulting interview transcripts were analysed with a dedicated coding scheme (see Appendix J2).

The following insights were gained from these interviews. Firstly, two out of three teachers claim procrastination is a significant factor contributing to poor performance in the course. One teacher observed that many students delay studying until just before the exam. Another, similarly, observes that students often underestimate the time and effort required to master the concepts and attempt to "cram it in the last week". While the last teacher did not mention procrastination, they did note that the most successful students consistently engage with the material throughout the course.

Secondly, two out of three teachers expressed concerns about students relying too heavily on the knowledge quizzes on HeatQuiz as a measure of exam preparedness. They observed that students prioritize memorizing HeatQuiz questions without engaging with more exam-level problems. This seems predominantly motivated by the bonus point system. One teacher argued this may lead students to develop a false sense of confidence about their level of understanding and ability to solve problems. Similarly, another emphasized that HeatQuiz serves best as a supplementary tool for reinforcing concepts after engaging with the primary learning materials, however, students may not use it as such.

And lastly, all teachers agree that students often do not focus on complex problem-solving tasks that reflect the exam’s demands. Two teachers structure their tutorials to prioritize problem-solving to provide students with opportunities to practice. However, they mention that attendance is often low so many students may miss out on this. Moreover, one teacher adds that some students might still be weak in foundational knowledge like energy balances that are necessary to solve heat transfer problems. This widens the gap between student understanding and exam requirements.

In conclusion, teachers indicate various factors that contribute to a gap between student understanding and exam requirements. To start, with the freedom to manage their studies, students tend to procrastinate their efforts until the last weeks of the course. Next, students may focus their efforts too much on HeatQuiz questions as a measure of exam preparedness. And finally, students may not spend enough time developing complex problem-solving skills they need to pass the exam.

Teaching assistants

A total of two TAs (n_{ta} = 3) were interviewed individually. This was also done in an online setting. The resulting interview transcripts were analysed with a dedicated coding scheme (see Appendix J3).

The following observations were made. Firstly, both TAs reported little student interaction. If it did occur, it was mainly during the tutorials and, occasionally, during the online forums on Canvas. One TA observed that many students came to the tutorials unprepared but still opted to work independently on exercises. When necessary, the minority would ask for help. This was corroborated by the other TA, who estimated that only around 10% of students actively reached out for help. Interactions focused mainly on clarifying learning tasks or addressing fundamental questions related to those tasks.

Secondly, both TAs observed a significant portion of students delaying their studies until the end of the course. One TA noted that students often postpone due to prioritizing other commitments. They mentioned that the project, especially, has more immediate deadlines that require students to keep up. The other adds that the readily available resources in HeatQuiz may cause a false sense of security that students can start learning at any point. As a result, many students attempt to catch up on the material in the final weeks.

Thirdly, both TAs argue that the bonus point system negatively impacts students' ability to master the course content. The first TA suggested that, while the bonus point system could encourage participation in the tutorials or using HeatQuiz, students might prioritize memorizing answers or completing tasks for the sake of earning bonus points. This is echoed by the second TA, who argues that the bonus points focus students' attention on the smaller exercises in HeatQuiz instead of the more complex problems in the course reader. This may lead to students believing that the materials on HeatQuiz are sufficient for developing the knowledge and skills to face the exam.

In summary, the TAs generally noticed an attitude toward learning in students that lowers their chances of passing the course. They argue this is, firstly, due to students not asking for help during tutorials or outside. Secondly, students postpone their studies due to other commitments or a false sense of security through resources being readily available online. Lastly, the bonus point system may direct students to learn more superficially as they focus on memorization of HeatQuiz questions rather than developing the ability to do complex problem-solving.

Addressing the research questions

RQ2.1: How do students engage in SRL behaviour?

Regarding the forethought phase, students appeared to face difficulties in effectively planning their studies. Teachers and TAs observed that most students tend to procrastinate their studying until the final weeks before the exam. Students reflected this indirectly, by mentioned that the study load was heavy or that the course lacked guidance. This resulted, in part, in a focus on one specific resource to be used as the primary learning tool, such as the reader or HeatQuiz, with the high chance of missing out on essential learning gained from other modalities. The bonus point system negatively influenced this process, as it pushed students to prioritize earning bonus points in the short-term rather than deeply understanding the key concepts and developing multi-step problem-solving skills. This could indicate that students are challenged in effectively planning their studying.

Regarding performance, students appeared to rarely evaluate if their study habits align with actual understanding. They frequently used HeatQuiz as their primary tool for measuring their understanding, despite its focus on single-step exercises and superficial feedback. Teachers observed that this may cause a false sense of mastery and, in turn, reduced engagement more exam-like problems found in the reader or old exams. Furthermore, TAs mentioned that only a small percentage of students actively asked questions or sought clarification regarding their understanding, either during in-person sessions or via the discussion forums. This could indicate that many students miss out on opportunities to monitor and adjust their approaches effectively.

Regarding self-reflection, students appeared to rarely reflect during their studying. There was a tendency for students to externalize the blame for the experienced difficulties onto a perceived lack of guidance, heavy workload, or unclear resources. In contrast, both teachers and TAs observed that students often appeared unprepared and tended to procrastinate their studying until the last moment. This could indicate that students are not sufficiently supported in reflecting on their actions and how it compares with learning outcomes.

RQ2.2: How do students engage in metacognitive calibration?

Students very rarely engaged in metacognitive calibration, and this could be due to several reasons. Firstly, students mentioned a tendency to procrastinate their studying until the final weeks of the course. The TAs believed that readily available online resources gave students a false sense of security. However, this behaviour reduced the number of available opportunities for metacognitive calibration and strategy adjustment until it was too late. Teachers mentioned that the low attendance to in-person sessions prevented students from receiving feedback on their progress, which could have been a trigger for learning strategy adjustment.

Secondly, students argued they received insufficient detailed feedback and guidance on how to solve multi-step problems. This made it challenging for them to know what to change in their learning approach. Teachers, however, noted that the lack of engagement with these complex problems was the major reason why students didn't receive the feedback they need to adjust their learning strategies. Furthermore, TAs observed that most students came to tutorials unprepared and rarely asked for feedback, in favour of working on simpler tasks from previous weeks. Compounded with the tendency to procrastinate, students may experience a pressure to catch up rather than focusing on learning in the most effective way.

Lastly, most students admitted to focusing on memorizing answers for bonus points rather than analysing their performance and change learning strategies if they were ineffective. Both teachers and TAs observed this behaviour and argued that many students perceive HeatQuiz quizzes as a valid proxy for exam preparedness, even though they discourage this.

Exploration

Alongside the Analysis activities, other perspectives on similar situations have been explored to construct a richer understanding of the challenges found in the Heat Transfer course. These perspectives came from two sources: (1) a panel of experts from the University of Twente, and (2) two teachers who have taught courses with a similar educational design.

The researcher met the panel of experts monthly to reflect on the research process. They provided their expertise in online learning environments, SRL, and uncertainty management to clarify findings from the field-based investigation.

Two teachers from alternate, but related course contexts have also been interviews. One teacher taught a course with a similar design, but different topic (Thermodynamics). The other teacher taught the Heat Transfer course at RWTH Aachen University, in a longer format (one semester instead of 10 weeks).

Observations from these Exploration activities have been incorporated in the Analysis activities and have influenced the synthesis of the Analysis & Exploration phase.

Synthesis

The Analysis & Exploration activities have led to four products: a refined problem statement, long-range goals, partial design requirements, and initial design propositions. These served as inputs for the next EDR phase.

Revised problem statement

As mentioned in the initial orientation to the research context, many students in the Heat Transfer course faced difficulties passing. Factors such as lack of motivation, ineffective time management, and low attendance in in-person classes have been pointed to as the root cause of these challenges. It was hypothesized that these behaviours occur due to students' underdeveloped SRL skills, particularly in areas such as monitoring and self-assessment.

Considering the data gathered in the Analysis and Exploration phase, however, this initial problem statement is inaccurate and requires revision. What follows are several results that describe challenges within the course's educational design that contribute to the key issue of students having difficulty passing the Heat Transfer course. This subsection ends with a revised problem statement.

Challenge 1: Partial implementation of the flipped classroom model

The course manual explains that the Heat Transfer course implements a flipped classroom model with a balance between self-study and in-class activities. In practice, however, there appears to be a partial implementation of the blended learning model, which may pose challenges to students with low SRL skills.

This finding is elaborated through the following observations. The document analysis shows that course materials are presented in a way that provides students with complete freedom in their preferred study strategy. This is enforced by the policy of in-person sessions being completely optional to attend. Therefore, it is possible to take the course up until the exam without ever having to step into a lecture hall. It also shows a lack of integration between online and in-class activities. For example, the course reader nor HeatQuiz contains any references to in-class activities. The teacher interviews indicate that the content for the in-person session may not always be directly sourced from the materials. This disconnect may make it difficult for students to estimate the value of the sessions and how to best prepare for them.

On the student level, a desire for more in-person sessions was expressed, while teachers and TAs mentioned that attendance rates were often low. When students do attend, they are often unprepared and prefer focusing on simpler tasks or revisiting topics from earlier weeks. Consequently, they fail to reap the intended benefits of in-person sessions. This indicates various SRL-related challenges, such as planning, goal setting, and preparation.

Challenge 2: Bonus point system leads to superficial learning

A bonus points system connected to HeatQuiz use was implemented to promote desired learning behaviour among students. On the positive end, various students have acknowledged that the bonus points were an incentive to engage with HeatQuiz. This helped them stay on track with the course schedule, as well as helped them practice with problem sets. However, the bonus point system has mainly led to negative effects on learning. To start, the bonus points led to students being more concerned with passing the quizzes to earn points rather than deep understanding. Some students mentioned that they felt more encouraged to memorize answers in pursuit of the points.

Moreover, it was mentioned that it was common for students to pass around answers instead of solving questions themselves. This led to students finishing quizzes in a fraction of the time it would take if they did it without support.

Finally, teachers and TAs expressed concerns that the focus on earning bonus points could lead to a false sense of mastery and exam preparedness. In their belief, the bonus point system encourages students to concentrate on simpler HeatQuiz exercises at the expense of the more complex, multi-step problems found in the course reader or in-person sessions. This false sense of mastery might especially be true for students who used HeatQuiz as a primary learning tool and did not attend any of the in-person sessions.

Challenge 3: Course design assumes overly high levels of SRL from the start

The interviews with teachers and TAs indicate a perception of students' SRL skills that does not align with students' SRL skills going into the course. This is also reflected in the course design, as the document analysis has shown a lack of built-in SRL support for many elements of the learning process. While students with higher levels of SRL skills may face no issues in the Heat Transfer course, students with less developed SRL skills may only discover their ineffective learning strategies when it is too late.

The lack of SRL support manifests in several ways. Firstly, students expressed a need for more explicit, step-by-step guidance for complex problem-solving. The course reader does describe a systematic problem-solving approach throughout the various chapters. However, this could easily be missed by students who did not make frequent use of the reader. The only place where students could receive this problem-solving guidance was during in-person sessions, which were not attended very often.

Secondly, the course materials lack explicit support for helping students navigate the resources and plan their study time. While there are elements (i.e. a checklist per topic in the reader, a visualized learning pathway in HeatQuiz) that provide support, they do not help students engage deeply enough with the materials to accurately plan, assess, and maintain their learning processes (planning, monitoring, self-reflection). Teachers have observed that students procrastinate often and spend the final weeks before the exam cramming the materials. TAs mentioned that students often struggle with complex problems but did not seek help. Given the course's low passing rate and the accounts of students having difficulties with the course, it can be argued that students require much more support to help them regulate their learning.

Finally, the course provides very few feedback mechanisms for students to monitor their progress. The two primary mechanisms are quizzes on HeatQuiz and in-person sessions. The quizzes on HeatQuiz offer immediate feedback on relatively simple questions but only focus on correctness rather than addressing misconceptions or offering strategies for improvement. This prevents students from accurately addressing their misunderstanding or changing their learning strategies. The in-person sessions provide students with corrective and cognitive feedback. However, the low attendance rates suggest that many students miss out on this opportunity. Moreover, TAs mentioned that the students who did show up rarely asked them for support and feedback.

Formulation of a more accurate problem statement

These insights show a more complete picture of the root causes of students' underperformance in the Heat Transfer course. Initially, factors such as lack of motivation, ineffective time management, and low student attendance were thought to be the reasons for students' underperformance. This was attributed to students' underdeveloped SRL skills.

However, the results have revealed three different factors associated with student underperformance in the course. Firstly, the course design partially implements the flipped classroom model and requires a large extent of self-regulation, which may significantly decrease the learning effectiveness for students with lower SRL skills. Secondly, the course design incorporates a bonus point system that may hinder meaningful learning and incentivize students to learn more superficially. Consequently, students gain a false sense of mastery, which may lead to underperformance during the exam, especially for students with lower SRL skills. Finally, the course design expects a higher level of SRL skills than many students possess coming into the course. This was reflected in the attitudes of teachers and TAs, as well as the lack of SRL support built into the course design. These three factors contribute to a learning environment where students with low SRL skills may face difficulties with engaging effectively with the course materials and, as a result, underperform.

Long-range goals

A guiding vision for interventions was developed to effectively address the issues mentioned in the revised problem statement (see Figure 6). Considering the Heat Transfer course involves various challenges, an overarching long-range goal is necessary to capture their essence and ensure interventions are designed to follow the same direction. This can then be subdivided into several smaller goals that directly address each challenge. It should be noted that the phrasings are purposefully kept broad and lacking in measurable criteria to allow for flexibility in the design and implementation of various interventions.

Figure 6

Long-Range Goals for the Heat Transfer Course

Long-range goals
Primary goal
"By the end of the Heat Transfer course, students are able to solve complex, multi-step Heat Transfer problems through scaffolded SRL support that promotes active engagement with all learning components of the course, frequent reflection on feedback, and continuous refinement of their learning strategies to deepen understanding and application of complex Heat Transfer concepts and successfully pass the exam."
Subgoals per challenge
Challenge: Partial implementation of the flipped classroom model **Subgoal 1**: "During the Heat Transfer course, students will be able to perceive the value of and effectively prepare for in-person sessions through clear guidance on connecting online content and in-person learning activities."
Challenge: Bonus point system leads to superficial learning **Subgoal 2**: "During the Heat Transfer course, students will be able to progressively develop multi-step problem-solving skills that align with exam requirements through scaffolding elements and incentive structures that promote a deep understanding of complex concepts and their application."
Challenge: Course design assumes overly high levels of SRL **Subgoal 3**: "During the Heat Transfer course, students will be able to frequently identify and reflect on their learning gaps and misconceptions after assessments or scaffolded learning activities to adjust their study strategies and improve their performance on course assignments and exercises."

Partial design requirements

To operationalize the long-range goals into relevant educational interventions, it is important to make explicit what criteria they should abide by based on the freedoms, opportunities, and constraints the educational setting of the Heat Transfer course affords. These partial design requirements (see Table 2) will guide general design choices and are meant to be refined during the design and construction phase.

Table 2

Partial Design Requirements for Educational Interventions

Freedoms	Opportunities	Constraints
Be able to provide multiple pathways for learners to engage with learning resources.	Should connect online learning content with in-class activities for cohesive learning.	Must progressively reduce scaffolding as learners develop proficiency by set standards.
Be able to allow progression through problem-solving exercises at each student's own pace.	Should guide the learning process through frequent, detailed, and actionable feedback.	Must align learning activities with exam requirements through real-world scenarios.
Be able to attempt learning activities as many times as needed with adequate feedback.	Should stimulate reflection on performance, misconceptions and learning strategies.	Must present a standardized approach to scaffolding across all learning materials and activities.

These partial design requirements have been formulated to address all the long-range goals. They help determine which aspects of the Heat Transfer course can be altered and which cannot. This approach ensures that each intervention is developed within the context of student, teacher, TA, and university needs.

Initial design propositions

Based on the revised problem statement, long-range goals, and partial design requirements, loose features of relevant educational interventions can already be offered. These initial design propositions seek to make the focus of any interventions more concrete upon which design choices can be made during the Design and Construction phase. In Table 3, each partial design requirement is translated into a more concrete initial design proposition.

Table 3

Initial Design Propositions for Educational Interventions

Partial Design Requirement	Initial Design Proposition
DR1: Be able to provide multiple pathways for learners to engage with learning resources.	**DP1**: The intervention should offer diverse learning resources across various modalities to allow learners to choose based on their preferences. It should provide guidance to ensure all pathways develop the necessary knowledge, skills, and attitudes for assessment.
DR2: Be able to allow progression through problem-solving exercises at each student's own pace.	**DP2**: The intervention should offer self-paced problem-solving exercises with progress tracking and formative assessments to indicate mastery. It should provide adaptive scaffolding (i.e. worked examples)

	for challenging concepts so learners can focus on areas of improvement.
DR3: Be able to attempt learning activities as many times as needed with adequate feedback.	**DP3**: The intervention should allow learners to attempt learning activities multiple times and incorporate formative feedback mechanisms to provide actionable guidance to learners. It should adapt feedback based on learner performance to focus on problem areas.
DR4: Should connect online learning content with in-class activities for cohesive learning.	**DP4**: The intervention should include resources that help learners build a foundation for in-class participation, such as providing pre-class readings, videos, and practical exercises. It should help students see the value and relevancy of attending in-person sessions and clearly refer or connect to those.
DR5: Should guide the learning process through frequent, detailed and actionable feedback.	**DP5**: The intervention should provide personalized feedback based on performance, with detailed explanations of and reasoning behind the correct and incorrect answers. It should make explicit connections to intended learning outcomes to indicate relevancy and importance.
DR6: Should stimulate reflection on performance, misconceptions, and learning strategies.	**DP6**: The intervention should stimulate students to articulate their thinking to identify misconceptions and how to address them. It should include reflection prompts or discussion forums to provide structured reflection opportunities.
DR7: Must progressively reduce scaffolding as learners develop proficiency by set standards.	**DP7**: The intervention offers task types (i.e. worked examples, completion, conventional) aligned with performance standards transparently communicated via rubrics. It should increase task complexity and gradually reduce scaffolding depending on student proficiency, with a mechanism for accessing additional support when necessary.
DR8: Must align learning activities with exam requirements through real-world scenarios.	**DP8**: The intervention should use real-world scenarios that mirror professional contexts to promote higher-order thinking and be scaffolded according to student proficiency levels. It should

	include reflective prompts, problem-solving guidance and detailed feedback.
DR9: Must present a standardized approach to scaffolding across all learning materials and activities.	**DP9**: The intervention should apply a scaffolding framework across all materials and activities that clearly defines task types (i.e. analysis, problem-solving) and levels of support (i.e. worked examples, conventional). It should sequence tasks from simple to complex and adjust scaffolding levels based on formative assessments of student proficiency.

These initial design propositions were used as a starting point for the design process. They aimed to help further focus on improving course materials, feedback mechanisms, and task complexity to match students' proficiency as they go through the Heat Transfer course.

Design & Construction

The Design and Construction phase built on the results of the previous phase and aimed to map potential solutions to the identified challenges in the Heat Transfer course. This was done in collaboration with the project team, mainly the project leader of the Heat Transfer course.

Design: Exploring solutions

The following subsections describe the first design process, namely exploring solutions that may effectively address the identified challenges in the course.

Generating ideas

Various ideas for interventions were generated. The primary method used for generating ideas was brainstorming. The researcher did this both alone and in three collaborative sessions with the project team. This occurred in various steps. Firstly, the researcher began by generating ideas based on the identified challenges, partial design requirements, and initial design propositions. The resulting ideas were then brought to the project team in collaborative brainstorming sessions. In each session, the researcher presented insights from the Analysis & Exploration phase as well as any generated ideas based on them. Project team members provided feedback and suggested alternative ideas when relevant. This brainstorming process has led to five ideas that each seek to address one of the three identified challenges found in the Heat Transfer course.

Integrated lesson plans seek to clarify the value of in-person sessions and help students better prepare and be able to participate. Incorporating SRL phases into the plans may promote self-regulation through problem-solving and reflection (Michalsky & Schechter, 2018), especially when combined with discovery learning (Sayukti, 2018). This could be in the shape of a standardized document that includes the main takeaways for that week's material, guiding questions to stimulate reflection, details on the session's content, and how the pre-class materials connect to hands-on classwork.

Guided video walkthroughs help students learn how to solve problems through expert demonstrations. Videos that clarify complex concepts and allow for repeated viewing are associated with improved motivation and engagement in the learning process (Cheng et al., 2024). They might further include guiding questions and reflective prompts to reinforce understanding (Van Alten et al., 2020). This allows students who do not attend in-person sessions to still benefit from the in-person sessions, where teachers often walk through exercises with the class.

More elaborate feedback would help students more deeply understand their errors and associated misconceptions they have about the course content (Enders et al., 2021). When including motivational aspects, it may also promote intrinsic motivation (Theobald & Bellhäuser, 2022). Feedback could include detailed explanations for both correct and incorrect answers, links to relevant resources, and actionable steps to address misconceptions. This can be embedded into HeatQuiz' current quizzes, however, this feedback structure could also be valuable for any other assignment students may need to hand in.

Process worksheets provide a scaffold to stimulate students to actively engage with systematic approaches to problem-solving (Widodo et al., 2023). Including prompts in problem-solving scenarios has been found to effectively develop cognitive structures (Ifenthaler, 2012). These could be provided as a tool students can use when doing exercises from the course reader or old exam questions.

Periodic formative assessments seek to provide students with frequent feedback moments through low-stakes, mastery-focused exercises. This has been associated with improved comprehension and active learning (Aligula, 2024). These assessments would be adapted to students' comprehension level at different points in the course. Students would do these assessments during the in-person sessions and discuss their results with peers to discuss problem-solving approaches and potential misconceptions.

Considering ideas

The five proposed ideas were systematically analysed and compared in a two-step process to distinguish their direct value within the Heat Transfer context and select the best fitting. In the first step, a weighted ranking matrix was created to evaluate each idea against the nine formulated partial design requirements (see Table 4). This was done using a weighted ranking of the ideas by partial design requirements. This method was selected to evaluate ideas based on the prioritization of certain design requirements by assigning different weights to each.

In the previous research phase, the design requirements were categorized into freedoms, opportunities, and constraints to reflect their alignment with the Heat Transfer course's context. "Freedoms" are freely alterable aspects, so they were assigned the lowest weight (1 point). "Opportunities" and "constraints", in contrast, are less flexible and were weighted higher (2 and 3 points, respectively). When the idea met a requirement, it received the corresponding number of points assigned. The final column shows the total.

Table 4

Weighted Ranking of Generated Ideas by Partial Design Requirements

	DR1 *Multiple engagement pathways*	**DR2** *Self-paced problem-solving*	**DR3** *Unlimited attempts with feedback*	**DR4** *Online-classroom integration*	**DR5** *Detailed feedback*	**DR6** *Stimulate learner reflection*	**DR7** *Progressive scaffold reduction*	**DR8** *Exam-like scenarios*	**DR9** *Standardized scaffolding approach*	**Total**
Integrated lesson plans	1	0	0	2	0	0	0	0	3	6
Guided video walkthroughs	1	1	0	0	0	2	0	3	3	10
More elaborate feedback	0	0	1	0	2	2	0	0	0	5
Process worksheets for guided problem-solving	0	0	0	0	0	2	3	3	3	11
Periodic formative assessments	0	1	0	0	2	2	0	3	0	8

The table show that process worksheets for guided problem-solving (11 points) and guided problem-solving walkthroughs (10 points) best meet the partial design requirements, such as aligning learning activities with exam requirements through real-world scenarios and presenting a standardized approach to scaffolding across all learning materials and activities. As such, these two ideas were further considered.

The second step consisted of an analysis of the remaining ideas according to the cyclical model of SRL (Zimmerman, 2008). This method was selected to evaluate ideas based on their potential to stimulate SRL behaviour to provide theoretical grounding and ensure the ideas had the potential to foster the intended behavioural change. The strengths and weaknesses of each idea were identified across the three SRL phases: forethought, performance, and self-reflection. An overview is found in Table 5.

Regarding video walkthroughs, providing hints to help students apply SRL strategies may make related SRL behaviours more likely (Van Alten et al., 2020; Moos & Bonde, 2016). Next, including examples of effective task-selection strategies to assess their own performance and select appropriate tasks based on their self-evaluation (Raaijmakers et al., 2017). Conversely, lack of feedback may limit the ability to identify and change learning strategies to address knowledge gaps (Yu et al., 2024).

Regarding process worksheets, focused prompts coupled with a single activity may promote planning behaviour (Burkholder et a., 2021). Moreover, guiding questions to select learning goals may help with task prioritization and self-reflection (Barak, 2009). However, students lacking in monitoring and self-reflection skills may have difficulties using worksheets to accurately calibrate their learning strategies (Hačatrjana & Linde, 2023).

Table 5

Theoretical Analysis by SRL Phase (Zimmerman, 2008)

	SRL phase		
Design idea	**Forethought**	**Performance**	**Self-reflection**
Guided video walkthroughs	**Strengths**: • Step-by-step instructions to help analyse tasks and set goals • Demonstrates systematic problem-solving to encourage strategic planning	**Strengths**: • Allows students to learn at their own pace to help with self-monitoring • Expert-level demonstrations allow students to model effective strategies	**Strengths**: • Shows a complete solution students can evaluate their own work against • Can include reflective prompts to encourage self-reflection and adjusting learning
	Weaknesses: • May lead to passive consumption and no real planning execution • May lead to a focus on procedural steps rather than how concepts connect to specific actions	**Weaknesses**: • Fails to provide personalized support in real-time • May limit opportunities for students to experiment with problem-solving approaches	**Weaknesses**: • May lead to a focus on imitation rather than a deeper understanding • Does not include feedback that could address individual misconceptions
Process worksheets for guided problem-solving	**Strengths**: • Step-by-step instructions to help analyse tasks and set goals per step • Guiding questions to help students use relevant concepts and plan accordingly	**Strengths**: • Reduces cognitive load through a step-by-step structure • Breaking down tasks into steps may support self-monitoring	**Strengths**: • Each step may help students evaluate their strategies and implementation. • Helps connect planning to their solution and understanding

	Weaknesses: • Simplified structure may reduce students' ability to analyse complex scenarios • May not be effective for more proficient students	**Weaknesses**: • Students may focus on completing steps rather than understanding • Breaking down tasks into steps may support self-monitoring	**Weaknesses**: • Does not include feedback that could address individual misconceptions • Usage may not necessarily lead to adjustment of learning strategies

The table shows that both ideas support SRL behaviours across all phases of the model. However, process worksheets appear more effective due to their balance between providing guidance and allowing for student agency. To start, process worksheets can help students not only actively plan and monitor their learning but also promote reflection and adjustment of strategies (Barak, 2009). In contrast, video walkthroughs may be consumed passively, which may lead to a dependence on external guidance. Additionally, walkthroughs do not necessarily lead to reflection and adjustment of strategies (Yu et al., 2024).

Moreover, process worksheets can be adapted to varying levels of learner proficiency, while video walkthroughs are more static. This adaptability aligns with best practices in SRL support, which emphasize the gradual transfer of responsibility from teacher to learner (Sirazieva et al., 2017). In contrast, video walkthroughs are more fixed, which may make it more challenging to accommodate different proficiency levels (Lange et al., 2022).

Checking ideas

The two ideas and their analyses were presented to the project leader by the researcher. After a discussion, it was decided upon to move forward with the idea of the process worksheet given its many SRL benefits and lower construction costs.

The next step entailed assessing the internal logic and viability of the process worksheets idea. This was done using a logic model, a structured representation of how an intervention is expected to function and produce desired outcomes (McKenney & Reeves, 2018). It was selected for its efficacy in mapping out the required inputs, processes, outputs, outcomes, and impact of the intervention if it were applied to the Heat Transfer course setting. The logic model for the process worksheet is found in Table 6.

Table 6

Logic Model of Process Worksheet Intervention Idea

Inputs *What is needed*	Processes *Activities*	Outputs *Immediate results*	Outcomes *Effects*	Impact *Measurable change*
• Step-by-step instructions for problem-solving tasks • Embedded reflection prompts to guide self-reflection • Teacher training on how to incorporate worksheets into in-person sessions • Access to digital and paper formats for students • Worked examples of worksheets	• Distribution through Canvas, HeatQuiz or in-person sessions • Teachers use worksheets during in-person sessions • Students use worksheets to practice with exam-like problems • Collection of student feedback to refine worksheets	• Improved performance in problem-solving exercises • Better quality participation during in-person sessions • More engagement with exercises and old exam questions	• Improved problem-solving strategies and metacognitive awareness • Higher student satisfaction with the learning experience • Improved SRL skills among students	• Higher exam grades • Increased course pass rates • Decreased course dropout rates

The logic model for process worksheets shows a viable pathway for improving students' SRL skills. To start, the essential inputs, such as step-by-step instructions, reflection prompts, and teacher training support implementation processes like worksheet distribution and integration into in-person sessions. Outputs such as improved problem-solving performance and increased engagement with exam-like exercises directly contribute to outcomes such as better SRL strategies and metacognitive awareness. With measurable impacts like higher exam grades and increased course pass rates, the model's internal logic appears to be strong.

Design: Mapping solutions

The following subsections describe the second design process, which mapped solutions to the partial design requirements and initial design propositions.

Refining design requirements and propositions

Based on the results from exploring solutions, the partial design requirements and initial design propositions were refined to better address the challenges found in the Heat Transfer course and provide a more concrete plan for the process worksheet. These are shown in Table 7.

Table 7

Refined Design Requirements and Propositions

Refined Design Requirement	Refined Design Proposition
DR1: Be able to provide multiple pathways for learners to engage with learning resources.	**DP1**: The intervention should offer diverse learning resources and guidance on how to use them across various modalities to allow learners to choose based on their learning preferences.
DR2: Be able to allow progression through problem-solving exercises at each student's own pace.	**DP2**: The intervention should offer self-paced problem-solving exercises with progress tracking, scaffolding, and feedback to indicate mastery.
DR3: Should connect online learning content with in-class activities for cohesive learning.	**DP3**: The intervention should link pre-class material to in-class tasks to help students see the value and relevancy of attending in-person sessions.
DR4: Should guide the learning process through actionable feedback that stimulates reflection on performance, misconceptions, and problem-solving strategies.	**DP4**: The intervention should provide elaborate feedback and insights into the reasoning process of both correct and incorrect answers, as well as reflective prompts based on performance to help students address misconceptions and refine problem-solving strategies.
DR5: Must progressively reduce scaffolding as learners develop proficiency by set standards.	**DP5**: The intervention must offer task types (i.e. worked examples, completion, conventional) aligned with performance standards communicated via rubrics, increase task complexity, and gradually reduce scaffolding depending on student proficiency.
DR6: Must align learning activities with exam requirements through real-world scenarios.	**DP6**: The intervention should use real-world scenarios that mirror professional contexts and exam-like problems to stimulate the development of complex problem-solving skills.
DR7: Must present a standardized approach to scaffolding across all learning materials and activities.	**DP7**: The intervention should apply a scaffolding framework across all materials and activities that clearly defines task types (i.e. analysis, problem-solving) and levels of support (i.e. worked examples, conventional).

Various changes have been made to reduce redundancy and clarify the purpose and use of each design requirement and proposition. DR5 and DR6 were merged to unify the focus on actionable feedback and reflection. DR3 was combined with DR5 to capture the idea of frequent reflection opportunities through elaborate feedback. DR9 was completely removed, as it seemed to overlap with DR7 and DR4.

Creating a skeleton design

The next step was to further specify the features of the intervention by distinguishing core from supporting ones. This was done using a skeleton design to help systematically identify components that require further specification (see Table 8).

Table 8

Skeleton Design of All Generated Ideas

Design task	Materials/resources	Activities/processes	Participation/implementation
Process worksheets for guided problem-solving	**Core**: • Step-by-step worksheets • Worked example • Course reader • HeatQuiz **Support:** • Reflection prompts • Canvas • How-to instruction • Supplemental resources links	**Core**: • Gradual reduction of scaffolding over time **Support**: • Collaborative problem-solving activities	**Core**: • Teachers or TAs provide worksheets in HeatQuiz, Canvas, and the course reader **Support**: • Teachers or TAs use worksheets during in-person sessions • Peer review of worksheets

By clearly distinguishing between core and supportive features, the intervention can prioritize and test the essential elements first before gradually introducing additional features.

Formulating detailed specifications

The final step consisted of formulating detailed design specifications that flesh out the core features identified in the skeleton design. These consist of two aspects that guided the construction effort: substantive and procedural specifications. Substantive specifications describe the finished intervention in detail, while procedural specifications outline the steps and processes for creating and implementing the intervention. They are found in Table 9.

Table 9

Detailed Specifications of the Process Worksheet Intervention

Substantive	Procedural
Content and structure	**Content analysis**
• Step-by-step problem-solving prompts • Sections that provide space to outline answers • Guiding questions to stimulate step completion	• Analyse materials to identify systematic approaches to problem-solving • Identify common challenges in problem-solving
Scaffolding	**Implementation**
• Different versions that support students at varying proficiency levels • Scaffolding is reduced as students become more proficient	• Highly scaffolded version is introduced first • Worksheets to be integrated with the reader, Canvas, and HeatQuiz • Worksheets to be used by teachers and TAs during in-person sessions
Usability	**Evaluation**
• Paper and digital • Minimal layout	• Student feedback is gathered to refine worksheets

Together with the project leader, the specifications were evaluated against the long-range goals, refined design requirements, and propositions. They appeared to be well-aligned except for a lack of feedback integration. After discussion, it was agreed by the researcher and project leader that the omission was acceptable for now.

Construction: Building initial prototypes

The process worksheets for guided problem-solving were constructed in collaboration with the project leader. To start, the process began with content analysis of the reader, HeatQuiz, and Canvas to identify systematic problem-solving approaches and common challenges faced by students. It was decided to take the five-step structure found in the reader (see Figure 7), found in subsection 3.1, as a basis for the worksheet.

Figure 7

Reader Excerpt from Subsection 3.1

Solving complex problems by use of balances:

- For a chosen/defined control volume for the energy balance
  - Ensure that the chosen element is representative of the entire domain, as seen in the analysis of fluid flow through a pipeline. Consider a lengthy pipe through which fluid flows steadily. When modeling the fluid behavior, ensure the infinitesimal element is located within the fluid itself rather than the pipe wall.

1 Setting up the balance:

- Define changes in the internal energy.
  - The temporal change of fluid temperature over the course of time.
- Define fluxes across the boundaries.
  - Diffusive heat transfer due to temperature gradients.
  - Advective heat transfer due to fluid motion.
  - External mechanisms, such as radiative heat transport from the sun.
- Define internal heat sources and sinks.
  - Chemical reactor where the fluid flows through a reaction vessel.

2 Defining the elements within the balance:

- Define the fluxes based on constitutive laws for conduction, convection, and radiation.
  - Fourier's law of heat diffusion: $\dot{q}'' = -\lambda \frac{\partial T}{\partial x}$.
  - Newton's law of cooling: $\dot{q}'' = \alpha \left(T_{\mathrm{w}} - T_{\mathrm{f}}\right)$.
  - Stefan-Boltzmann Law: $\dot{q}'' = \sigma \epsilon T^4$.

3 Inserting and rearranging:

- Substitute all definitions and rewrite the differential equation in a clear manner.

4 Defining the boundary and/or initial conditions:

- Find the required conditions for solving the given differential equation.

5 Solving the equation:

- Using the boundary and initial conditions, find a mathematical expression for the required function.

Next, the worksheet was constructed with structured scaffolding to guide students progressively through the five steps. Each step includes a clear prompt and reflective question to guide students in the right direction. For example, Step 1 prompts students to start the problem-solving process by setting up the balance with a reflective question that guides them to identify the control volume of a given problem scenario. These prompts and questions were derived from the theoretical knowledge found in the reader and modified by the project leader for accuracy (see Figure 8).

Figure 8

First Version of Process Worksheet

Exercise Worksheet

Use this worksheet to practice solving complex heat transfer problems systematically. Following the 5 steps, you can more easily identify core issues, apply relevant concepts, and demonstrate your reasoning across various scenarios. Regular practice will lead to more accurate solutions and a deeper understanding of heat transfer principles. Good luck!

Step 1: Setting up the balance *What control volume represents the system you are analyzing?*
Step 2: Defining the elements within the balance *What energy fluxes exist across the boundaries of your defined control volume?*
Step 3: Inserting and rearranging *Has the differential equation been written clearly, and have all terms been included?*
Step 4: Defining the boundary and/or initial conditions *What are necessary boundary conditions (e.g. temperatures or heat fluxes at the system boundaries) and/or initial conditions (e.g. initial temperature distribution)?*
Step 5: Solving the equation *What mathematical expression makes physical sense given the boundary and/or initial conditions?*

In addition, the worksheet was renamed “exercise worksheet” to more clearly indicate to students its use, as well as a short description to demonstrate the value. It’s important to note that the layout was deliberately kept minimal and intuitive, with separate sections for each step to allow students to write their responses.

Two alternate versions of the worksheet were created to offer different levels of scaffolding. First, a high-scaffolded version was constructed to provide more detailed guidance (see Figure 9).

Figure 9

High-Scaffolded Version of Process Worksheet

Exercise Worksheet (High Scaffold)

Use this worksheet to practice solving complex heat transfer problems systematically. Following the 5 steps, you can more easily identify core issues, apply relevant concepts, and demonstrate your reasoning across various scenarios. Regular practice will lead to more accurate solutions and a deeper understanding of heat transfer principles. Good luck!

Step 1: Setting up the balance
What control volume represents the system you are analyzing?

- *Determine the specific amount of matter or area in space*
- *Outline the boundaries of the control volume*
- *Establish if the system is open or closed*
- *Sketch the control volume and its surroundings*

Step 2: Defining the elements within the balance
What energy fluxes exist across the boundaries of your defined control volume?

- *Determine which heat transfer modes are relevant: conduction, convection, and radiation*
- *Apply the correct physical laws to calculate the heat transfer*
- *Use the correct sign conventions*
- *Look for simplifications when possible*

Step 3: Inserting and rearranging
Has the differential equation been written clearly, and have all terms been included?

- *Replace flux terms with expressions from constitutive laws*
- *Rearrange to clarify relationships between physical parameters*
- *Check dimensional consistency and unit alignment*
- *Finalize the differential equation*

Step 4: Defining the boundary and/or initial conditions
What are necessary boundary conditions (e.g. temperatures or heat fluxes at the system boundaries) and/or initial conditions (e.g. initial temperature distribution)?

- *Identify the number of boundary conditions needed*
- *If known, state temperatures at a specific location*
- *If known, use symmetry or adiabatic conditions*
- *If known, derive the boundary condition from a local energy balance*
- *Consider if the conditions are physically plausible for the system*

Step 5: Solving the equation
What mathematical expression makes physical sense given the boundary and/or initial conditions?

- *Apply analytical or numerical methods to solve the differential equation and satisfy the boundary conditions*
- *Use initial conditions to determine the constants of integration*
- *Verify if the solution makes physical sense and satisfied all imposed conditions*
- *Explain the physical implications of the solution*

This version is constructed for students unfamiliar with the problem-solving approach recommended in the course or who have difficulties learning how to apply it. Each step includes specific actions to take to complete each step.

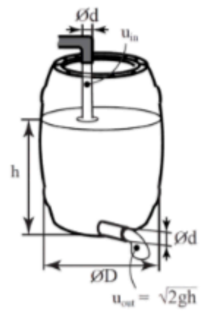
Second, a version to be used as a completion task was constructed to prepare students for exam-like scenarios with scaffolding (see Figure 10). Students are given a partially completed solution and are required to complete the remaining steps using their understanding of the theory and problem-solving skills.

Figure 10

Completion Task Version of Process Worksheet

Completion Task

Scenario: A fluid flows into the top of a barrel at a constant average velocity u_{in}. At the same time, a portion leaves the barrel through a pipe at a velocity u_{out}. Initially, the height of the fluid is equal to h0. Find an expression for the height *h*(t) of the fluid over time.



Step 1: Setting up the balance *What control volume represents the system you are analyzing?*
Step 2: Defining the elements within the balance *What energy fluxes exist across the boundaries of your defined control volume?*
Step 3: Inserting and rearranging *Has the differential equation been written clearly, and have all terms been included?* $\frac{dh}{dt} = \left(\frac{d}{D}\right)^2 \left(u_{in} - \sqrt{2gh(t)}\right).$
Step 4: Defining the boundary and/or initial conditions *What are necessary boundary conditions (e.g. temperatures or heat fluxes at the system boundaries) and/or initial conditions (e.g. initial temperature distribution)?* The height *h* has been differentiated once with respect to *t* and as such an initial water level (*h*) will be required to provide a solution to the problem. Initially: $h(t = 0) = h_0.$
Step 5: Solving the equation *What mathematical expression makes physical sense given the boundary and/or initial conditions?* Using an ODE solver, the following relationship is found:

These versions of the worksheet allow students to develop their ability to plan, monitor, and reflect on their problem-solving approach. By providing the appropriate version according to their proficiency level, students may gradually transition from guided learning to independent problem-solving.

Construction: Implementation perspective

During the construction of the process worksheets, the educational context and the practicalities of actual use in the Heat Transfer course were considered. Though not a full-on implementation plan, this section addressed various factors that may help or hinder the impact of piloting the worksheets.

The first consideration was the integration with existing course materials. The worksheets were designed to provide students with structured opportunities to practice multi-step problem-solving independently or to be used in tutorials to more easily follow along with the teacher as they walk through complex problems. The flexibility of the worksheets has also left room for it to be used to present exercises in a more scaffolded way, as found in the reader or old exams.

The second consideration was the iterative nature of the implementation. As worksheets haven't been used before, the initial version was constructed with adaptability in mind. This allowed for the structure, the prompts, or guiding questions to be refined based on observed use and student feedback.

The final consideration was accessibility and usability. The worksheets were designed to be clear and straightforward to minimize confusion, while also promoting complex problem-solving. It also fits a single A4 page, which was made to be available on Canvas, HeatQuiz and in the course reader to be downloaded and used digitally or printed.

Evaluation & Reflection

The Evaluation and Reflection phase aims to evaluate the process worksheets in the Heat Transfer course. Reflections on the evaluation findings are made to iterate development of the intervention and develop theoretical understanding. However, given the project's time constraints, this was out of scope. Therefore, an evaluation plan is proposed to guide a micro-cycle of this phase.

Evaluation: Planning

Establishing focus

The focus for this proposed evaluation cycle follows the long-range goal that the intervention should be able to help students progressively develop multi-step problem-solving skills through scaffolding elements. Considering that the intervention is an untested prototype, it is recommended to do an empirical test in the real-world context of a running Heat Transfer course. Relevant foci to consider are (1) the local viability to clarify usability and perceived value for all stakeholders, and (2) institutionalization to understand if and how teachers and TAs adopt the intervention and to what extent it integrates well with the existing course materials.

Framing questions

Specific research questions were formulated to guide the evaluation.

- How accessible are the instructions and prompts in the worksheets for students at varying proficiency levels?
- How well do the worksheets support the existing curriculum and in-person sessions?
- What factors influence students to use or not use the worksheets during their learning process?
- What changes do students, teachers, and TAs suggest for improving the content or structure of the worksheets?

Selecting strategies

A beta test in the form of a tryout is suggested as the evaluation strategy to study the functionality of the intervention in-depth, and how students interact with it during a complete Heat Transfer course. This is appropriate given how the prototype is complete enough to be used in a naturalistic context. Moreover, a tryout during a complete course could reveal different usage patterns during different points in the course, as well as implementation issues that could be used to further refine the intervention.

Determining methods

A qualitative research approach is recommended to better understand how the intervention is received during the tryout. Two data collection methods are proposed to facilitate this: observations, and semi-structured interviews.

First, structured observations by teachers and TAs during class sessions are proposed to understand how students engage with the worksheets and how it helped them engage with multi-step problems, such as the exercises in the reader or old exam questions. Teachers and TAs would need to be trained on a protocol to learn how to systematically do this. A starting point for what this protocol could look like is found in Appendix L1.

Second, semi-structured interviews are suggested to learn more about how students perceive the value of the worksheets and to what extent they engage with them. This may uncover if students understand their intended purpose and how to use them. A preliminary interview guide can be found in Appendix L2.

Document plan

In Table 10, an overview of the activities and timeline for the evaluation of the process worksheets during a running Heat Transfer is found.

Table 10

Timeline of Proposed Intervention Evaluation

Phase	**Timeline**	**Activity**
Preparation	Week 0	Create interview guides and informed consent forms
		Develop protocol for structured observations
		Train teachers and TAs on structured observation protocol
Data collection	Week 1 – 9	Conduct structured observations during tutorial sessions
	Week 7-9	Conduct semi-structured interviews with students
Analysis	Post-course	Compile observation notes, questionnaire responses
		Transcribe interviews
		Perform analyses on the collected data

References

Alexander, P. A. (2013). Calibration: What is it and why it matters? An introduction to the special issue on calibrating calibration. *Learning and Instruction*, *24*, 1–3. https://doi.org/10.1016/j.learninstruc.2012.10.003

Aligula, E. (2024). Rethinking higher education in Africa: Benefits of formative feedback in enhancing student learning. *Journal of Education*, *4*(5), 23–34. https://doi.org/10.70619/vol4iss5pp23-34

Alkhalaf, M. (2023). Flipped classroom approach in EFL context: Implementing self-regulated learning to improve students' performance in use of grammar. *International Journal of English Language and Literature Studies*, *12*(3), 238–253. https://doi.org/10.55493/5019.v12i3.4869

Anthonysamy, L. (2021). The use of metacognitive strategies for undisrupted online learning: Preparing university students in the age of pandemic. *Education and Information Technologies, 26*(6), 6881–6899. https://doi.org/10.1007/s10639-021-10518-y

Ashraf, M. A., Yang, M., Zhang, Y., Denden, M., Tlili, A., Liu, J., Huang, R., & Burgos, D. (2021). A systematic review of systematic reviews on blended learning: Trends, gaps and future directions. *Psychology Research and Behaviour Management, 14*, 1525–1541. https://doi.org/10.2147/PRBM.S331741

Barak, M. (2009). Motivating self-regulated learning in technology education. *International Journal of Technology and Design Education*, *20*(4), 381–401. https://doi.org/10.1007/s10798-009-9092-x

Bayyat, M., Abu Muaılı, Z. H., & Aldabbas, L. (2021). Online component challenges of a blended learning experience: A comprehensive approach. *Turkish Online Journal of Distance Education, 22*(4), 277-294. https://doi.org/10.17718/tojde.1002881

Burkholder, E., Mohamed-Hinds, N., & Wieman, C. (2021). Evidence-based principles for worksheet design. *The Physics Teacher*, *59*(6), 402–403. https://doi.org/10.1119/5.0020091

Cheng, S. F., Cheng, C. W., Hung, C. Y., & Chang, P. H. (2024). Effect of case-based teaching videos on e-learning platforms on the self-regulated learning outcomes of students*. Social Work Education*, 1–21. https://doi.org/10.1080/02615479.2024.2310586

Du, J., Hew, K. F., & Li, L. (2023). Do direct and indirect recommendations facilitate students' self-regulated learning in flipped classroom online activities? Findings from two studies. *Education Sciences, 13*(4), Article 400. https://doi.org/10.3390/educsci13040400

Eggers, J. H., Oostdam, R., & Voogt, J. (2021). Self-regulation strategies in blended learning environments in higher education: A systematic review. *Australasian Journal of Educational Technology*, *37*(6), 175-192. https://doi.org/10.14742/ajet.6453

ElSayad, G. (2024). Drivers of undergraduate students' learning perceptions in the blended learning environment: The mediation role of metacognitive self-regulation. *Education and Information Technologies*. https://doi.org/10.1007/s10639-024-12466-9

Enders, N., Gaschler, R., & Kubik, V. (2021). Online quizzes with closed questions in formal assessment: How elaborate feedback can promote learning. *Psychology Learning & Teaching*, *20*(1), 91–106. https://doi.org/10.1177/1475725720971205

Güzer, B., & Caner, H. (2014). The past, present and future of blended learning: An in depth analysis of literature. *Procedia - Social and Behavioural Sciences, 116*, 4596-4603. https://doi.org/10.1016/j.sbspro.2014.01.992

Hačatrjana, L., & Linde, I. (2023). Piloting supplementary materials aimed at developing students' problem-solving and self-regulated learning skills. *International Journal of Learning, Teaching and Educational Research*, *22*(6), 475–493. https://doi.org/10.26803/ijlter.22.6.25

Hacker, D. J., & Bol, L. (2019). Calibration and self-regulated learning: Making the connections. In J. Dunlosky & K. A. Rawson (Eds.), *The Cambridge handbook of cognition and education* (pp. 647–677). Cambridge University Press. https://doi.org/10.1017/9781108235631.026

Ifenthaler, D. (2012). Determining the effectiveness of prompts for self-regulated learning in problem-solving scenarios. *Educational Technology & Society*, *15*(1), 38–52.

Lange, C., Gorbunova, A., Shmeleva, E., & Costley, J. (2022). The relationship between instructional scaffolding strategies and maintained situational interest. *Interactive Learning Environments*, *31*(10), 6640–6651. https://doi.org/10.1080/10494820.2022.2042314

Liu, Y., Ma, S., & Chen, Y. (2024). The impacts of learning motivation, emotional engagement, and psychological capital on academic performance in a blended learning university course. *Frontiers in Psychology, 15*, Article 1357936. https://doi.org/10.3389/fpsyg.2024.1357936

Mayring, P. (2014*). Qualitative content analysis: Theoretical foundation, basic procedures and software solution*. Klagenfurt. http://nbn-resolving.de/urn:nbn:de:0168-ssoar-395173

McKenney, S., & Reeves, T. (2018). *Conducting educational design research*. Routledge.

Michalsky, T., & Schechter, C. (2018). Teachers' self-regulated learning lesson design: Integrating learning from problems and successes. *The Teacher Educator*, *53*(2), 101–123. https://doi.org/10.1080/08878730.2017.1399187

Moos, D. C., & Bonde, C. (2015). Flipping the classroom: Embedding self-regulated learning prompts in videos. *Technology, Knowledge and Learning*, *21*(2), 225–242. https://doi.org/10.1007/s10758-015-9269-1

Muhria, L., Supriatna, N., & Nurfirdaus, N. (2023). Students' challenges of blended learning model in higher education. *Journal Corner of Education, Linguistics, and Literature, 2*(3), 223–233. https://doi.org/10.54012/jcell.v2i3.123

Nikolopoulou, K., & Zacharis, G. (2023). Blended learning in a higher education context: Exploring university students' learning behaviour. *Education Sciences, 13*(5), 514. https://doi.org/10.3390/educsci13050514

Onodipe, G., Keengwe, J., & Cottrell-Yongye, A. (2020). Using learning management system to promote self-regulated learning in a flipped classroom. *Journal of Teaching and Learning With Technology*, *9*(1). https://doi.org/10.14434/jotlt.v9i1.29375

Palinkas, L. A., Horwitz, S. M., Green, C. A., Wisdom, J. P., Duan, N., & Hoagwood, K. (2015). Purposeful sampling for qualitative data collection and analysis in mixed method implementation research. *Administration and Policy in Mental Health and Mental Health Services Research, 42*(5), 533–544. https://doi.org/10.1007/s10488-013-0528-y

Pamuk, İ., & Alagözlü, N. (2024). A study on self-regulated learning in a flipped classroom model of EFL writing instruction. *Bartın University Journal of Faculty of Education, 13*(1), 120-133. https://doi.org/10.14686/buefad.1131031

Panadero, E. (2017). A review of self-regulated learning: Six models and four directions for research. *Frontiers in Psychology, 8*, Article 422. https://doi.org/10.3389/fpsyg.2017.00422

Raaijmakers, S. F., Baars, M., Schaap, L., Paas, F., van Merriënboer, J., & van Gog, T. (2017). Training self-regulated learning skills with video modeling examples: Do task-selection skills transfer? *Instructional Science, 46*(2), 273–290. https://doi.org/10.1007/s11251-017-9434-0

Rasheed, R. A., Kamsin, A., & Abdullah, N. A. (2020). Challenges in the online component of blended learning: A systematic review. *Computers & Education*, *144*, Article 103701. https://doi.org/10.1016/j.compedu.2019.103701

Rohlfs, W., Venner, C. H., Alouri, M., Kuiphuis, D. J. G., & Kneer, R. (2023). HeatQuiz: Combining flipped-classroom, game-based learning, and systematic problem analysis in heat transfer education. In *Proceedings of the 17th International Heat Transfer Conference*. https://doi.org/10.1615/IHTC17.70-20

Sayukti, N. K. H. (2018). Integrating self-regulated learning and discovery learning into English lesson plan. *SHS Web of Conferences*, *42*, Article 00047. https://doi.org/10.1051/shsconf/20184200047

Sirazieva, L. M., Fakhrutdinova, R. A., Kamasheva, J. L., & Leikin, M. (2017). Self-regulated learning in higher education. *Revista Publicando*, *4*(13(2)), 691–699. https://revistapublicando.org/revista/index.php/crv/article/view/930

Srivastava, N., Fan, Y., Rakovic, M., Singh, S., Jovanovic, J., van der Graaf, J., Lim, L., Surendrannair, S., Kilgour, J., Molenaar, I., Bannert, M., Moore, J. D., & Gašević, D. (2022). Effects of internal and external conditions on strategies of self-regulated learning: A learning analytics study. In *Proceedings of the 12th International Learning Analytics and Knowledge Conference (LAK22)* (pp. 392–403). Association for Computing Machinery. https://doi.org/10.1145/3506860.3506972

Stoten, D. W. (2019). Metacognition, calibration, and self-regulated learning: An exploratory study of undergraduates in a business school. *Learning: Research and Practice*, *5*(1), 24–47. https://doi.org/10.1080/23735082.2018.1491616

Theobald, M., & Bellhäuser, H. (2022). How am I going and where to next? Elaborated online feedback improves university students' self-regulated learning and performance. *The Internet and Higher Education*, *55*, Article 100872. https://doi.org/10.1016/j.iheduc.2022.100872

Tobler, S., & Kapur, M. (2023). Metacognitive calibration: A methodological expansion and empirical application. In P. Blikstein, J. Van Aalst, R. Kizito, & K. Brennan (Eds.), *Proceedings of the 17th International Conference of the Learning Sciences - ICLS 2023* (pp. 3-10). International Society of the Learning Sciences. https://doi.org/10.22318/icls2023.352932

Tuononen, T., Hyytinen, H., Räisänen, M., Hailikari, T., & Parpala, A. (2023). Metacognitive awareness in relation to university students' learning profiles. *Metacognition and Learning, 18*, 37–54. https://doi.org/10.1007/s11409-022-09314-x

Turner, R., Webb, O., & Pritchard, C. (2023). 'A freedom of students to choose': Student and staff perspectives on the future role of online learning in higher education. *Innovations in Education and Teaching International*, 1–20. https://doi.org/10.1080/14703297.2023.2292074

Uz, R., & Uzun, A. (2018). The influence of blended learning environment on self-regulated and self-directed learning skills of learners. *European Journal of Educational Research, 7*(4), 877-886. https://doi.org/10.12973/eu-jer.7.4.877

Van Alten, D. C. D., Phielix, C., Janssen, J., & Kester, L. (2020). Self-regulated learning support in flipped learning videos enhances learning outcomes. *Computers & Education*, *158*, Article 104000. https://doi.org/10.1016/j.compedu.2020.104000

Van Laer, S., & Elen, J. (2017). In search of attributes that support self-regulation in blended learning environments. *Education and Information Technologies, 22*, 1395–1454. https://doi.org/10.1007/s10639-016-9505-x

Wu, X. Y. (2024). Unveiling the dynamics of self-regulated learning in project-based learning environments. *Heliyon, 10*(5), Article e27335. https://doi.org/10.1016/j.heliyon.2024.e27335

Xu, Z., Zhao, Y., Liew, J., Zhou, X., & Kogut, A. (2023). Synthesizing research evidence on self-regulated learning and academic achievement in online and blended learning environments: A scoping review. *Educational Research Review, 39*, Article 100510. https://doi.org/10.1016/j.edurev.2023.100510

Yu, B. (2023). Self-regulated learning: A key factor in the effectiveness of online learning for second language learners. *Frontiers in Psychology*, *13*, 1051349. https://doi.org/10.3389/fpsyg.2022.1051349

Yu, A. S., Henderson, M., & Dang, T. K. A. (2024). Challenges for being self-directed in content and language integrated learning with instructional videos. In T. Cochrane, V. Narayan, E. Bone, C. Deneen, M. Saligari, K. Tregloan, & R. Vanderburg (Eds.), *Navigating the terrain: Emerging frontiers in learning spaces, pedagogies, and technologies. Proceedings ASCILITE 2024* (pp. 147–155). ASCILITE. https://doi.org/10.14742/apubs.2024.1224

Zhao, L., & Ye, C. (2020). Time and performance in online learning: Applying the theoretical perspective of metacognition. *Decision Sciences Journal of Innovative Education*, *18*(3), 435-455. https://doi.org/10.1111/dsji.12216

Zimmerman, B. J. (2008). Investigating self-regulation and motivation: Historical background, methodological developments, and future prospects. *American Educational Research Journal*, *45*(1), 166–183. https://doi.org/10.3102/0002831207312909

Appendices

Appendix A: Coding schemes

Table A1: Design

Coding Scheme for Design Analysis

Theory	Category	Code	Definition	Coding rule
Self-regulated learning	Forethought	Task prioritization	How students organize their tasks in order of importance.	Use when guidance on ordering tasks occurs or is mentioned.
		Time management	How students organize their study hours.	Use when time management strategies are given.
	Performance	Assessment	Tasks that test students' understanding of course content.	Use when evaluations (i.e. quizzes) are mentioned.
		Progress tracking	Tools or methods student use to monitor their learning progress.	Use when monitoring progress methods are suggested.
	Self-reflection	Error analysis	How students review their mistakes on assessments.	Use when reflecting on mistakes is proposed.
		Self-assessment	How students reflect on their knowledge and abilities.	Use when evaluation of understanding is prompted.
Metacognitive calibration	Judgment of learning	Learning strategy evaluation	How students reflect on their learning strategy.	Use when learning strategy (i.e. tips) is mentioned

		Confidence rating	How students rate their confidence in themselves during or after a task.	Use when confidence in answers is prompted.
	Performance feedback	Immediate feedback	Feedback provided to students right after task completion.	Use when feedback is provided right after task completion.
		Detailed feedback	Feedback that includes explanations of correct/incorrect answers.	Use when feedback includes explanations of correct/incorrect answers.
	Learning strategy adjustment	Reattempting tasks	If students can or attempt to redo tasks after receiving feedback.	Use when task reattempts are possible.
		Feedback integration	If students integrate feedback into future learning activities.	Use when feedback integration is encouraged.
Blended learning	Online	Self-paced learning	How students control the pace of their learning in an online setting.	Use when tasks have no fixed timelines or deadlines.
		Online resources	Availability of digital tools or content for further learning.	Use when any digital tools or content is mentioned.
	In-person	Instructor-led learning	In-class or in-person learning led by an instructor	Use when an instructor provides explanations or feedback.
		Collaborative learning	If students engage in group work or discussions	Use when peer collaboration is mentioned.
	Blended	Activity integration	Alignment between online and in-class activities.	Use when online and in-class tasks transition into each other.

		Cross-modality reinforcement	Reinforced learning using multiple educational formats.	Use when online and in-class tasks are repeated.

Table A2: Content

Coding Scheme for Content Analysis

Theory	Category	Code	Definition	Coding rule
Self-regulated learning	Forethought	Task prioritization	How students are guided to focus on specific tasks or topics in a recommended order.	Use when the content suggests the order of topics or highlights areas to prioritize.
		Concept structuring	How concepts are organized to support student understanding and learning goals.	Use when the content presents an organized structure of ideas like an overview.
	Performance	Comprehension checking	Prompts to help students check their understanding of theoretical content as they progress.	Use when educational elements encourage students to verify their understanding.
		Active engagement	Activities or tasks that encourage students to actively apply theoretical content.	Use when the content requires students to solve problems related to the topic at hand.
	Self-reflection	Reflective prompts	Prompts encouraging students to reflect on their learning after engaging with the content.	Use when the content contains questions prompting students to reflect on the content.

Metacognitive calibration	Pre-task prediction	Predicting understanding	Encourages students to estimate how well they understand a topic before engaging with the topic.	Use when the content prompts students to assess their understanding before engaging.
		Estimating difficulty	Prompts that ask students to anticipate how difficult a particular topic or task may be before starting it.	Use when the content suggests students estimate the difficulty of a section.
	Self-observation	Reviewing misunderstandings	Prompts students to review their misunderstandings after receiving feedback.	Use when the content prompts students to review answers to correct misunderstandings.
	Post-task reflection	Calibration reflection	Encourages students to compare their predicted understanding or performance with actual results after task completion.	Use when students are asked to reflect on how their predictions align with performance on tasks.
Blended learning	Online	Online resources	References to supplementary online materials to support learning.	Use when the content mentions online resources (such as HeatQuiz or videos) students can use.
	Blended	Activity integration	How online and offline activities are connected.	Use when the content suggests integrating online and offline resources for learning.
		Cross-modality reinforcement	Reinforces learning by using different types of resources, such as text, quizzes, and videos.	Use when the content suggests different types of resources to understand the material.

Appendix B: Document Analysis Codebooks

Table B1: Course Manual

Course Manual Codebook

Code	Excerpt
Task prioritization	"To maximize your learning experience, we recommend completing the assigned micro-lectures, quizzes, and homework from HeatQuiz before each lecture."
Time management	"The reduced number of lectures and exercise sessions in comparison to other courses is intentional, allowing you ample time to engage with the provided reader, watch video lectures, and delve into the material at your own pace." "This preparation enables you to participate actively in the exercise sessions, where you can seek clarification and delve deeper into specific assignments." "Simulate exam conditions: Time yourself to gauge your efficiency and progress."
Assessment	"The course culminates in a written exam, where you'll have the opportunity to demonstrate your understanding of heat transfer principles and their applications." "Homework tasks increase in difficulty stepwise and work towards the level required for the exam." "The tasks in the T-blocks are ordered in such a way that the level of difficulty increases stepwise toward the level required for the exam."
Progress tracking	"To accurately track and record your progress, and to qualify for bonus points, it's crucial to enter your student number in the provided field." "HeatQuiz automatically transmits your responses to our server, allowing continuous monitoring of your progress."
Error analysis	"Review your answers critically: After completing an exam, compare your solutions with the provided answers. Writing down your solutions is key to effective learning and self-assessment."

Self-assessment	"Writing down your solutions is key to effective learning and self-assessment."
Learning strategy evaluation	"Set Your Learning Objectives: Before diving into a movie or chapter, take a moment to review the learning goals and comprehension questions for that section." "Use the answers from the quizzes and HeatQuiz to adjust your learning strategies for future sections and the exam."
Confidence rating	-
Immediate feedback	"HeatQuiz provides you with quizzes, allowing you to check your understanding immediately after micro-lectures."
Detailed feedback	"Feedback includes explanations for incorrect answers in quizzes and assignments."
Reattempting tasks	"Students are encouraged to reattempt HeatQuiz quizzes to improve their understanding before progressing to T-block problems."
Feedback integration	"Use the answers from the quizzes and HeatQuiz to adjust your learning strategies for future sections and the exam."
Self-paced learning	"The reduced number of lectures and exercise sessions in comparison to other courses is intentional, allowing you ample time to engage with the provided reader, watch video lectures, and delve into the material at your own pace."
Online resources	"HeatQuiz is a platform with game-based elements for learning heat and mass transfer… you will have access to micro-lectures, quizzes, and homework tasks."
Instructor-led learning	"We will host five lecture sessions focusing on summarizing and synthesizing course content, rather than introducing new material."
Collaborative learning	"Discussion pages are available on Canvas where you can post queries related to Heat Transfer content. Student assistants will actively monitor these pages and respond promptly."
Activity integration	"The homework from each week consists of watching the micro-lectures and solving the corresponding quizzes, which can be seen in the so-called L-blocks."

Cross-modality reinforcement	"The T-blocks denote homework tasks. These tasks increase in difficulty stepwise and work towards the level that is required for the exam."

Table B2: Course Reader

Course Reader Codebook for Part I and Part II

Code	Element
Task prioritization	Learning goals at the start of each (sub)section act as guides for prioritizing tasks.
Concept structuring	Hierarchical structuring of concepts, with broad concepts introduced first (i.e. thermodynamics), followed by specific concepts (i.e. conduction). Sections are numbered with subheadings (i.e. 2.1 Fourier's law and 2.2 Steady-state temperate profile) to provide a clear path.
Comprehension checking	Comprehension questions at the beginning of each (sub)section allow students to check their understanding of key concepts
Active engagement	The "Phenomena" elements may prompt engagement as they link theory to real-world scenarios.
Reflective prompts	-
Predicting understanding	-
Estimating difficulty	-
Reviewing misunderstandings	-
Calibration reflection	-
Online resources	The reader references HeatQuiz at the start and end of certain sections.

Activity integration	The reader references quizzes via HeatQuiz to reinforce learning. However, it is not always evident to what extent activities are integrated.
Cross-modality reinforcement	The reader offers mainly text-based content, with some integration of micro-lectures, slides, and quizzes via HeatQuiz.

Table B3: Canvas

Canvas Codebook

Code	Element
Task prioritization	-
Concept structuring	-
Comprehension checking	The practice exams and solutions provide exam-level practice material.
Active engagement	The HeatQuiz tool is used to promote active engagement with course materials. The “Discussions” section is used to interact with teachers and TAs.
Reflective prompts	-
Predicting understanding	-
Estimating difficulty	-
Reviewing misunderstandings	-
Calibration reflection	-
Online resources	Various online resources are made available on the “modules” page, under the subheading “Resources”: course manual, reader, exercise bundle, book of formularies, solution bundle, and exam bundle)

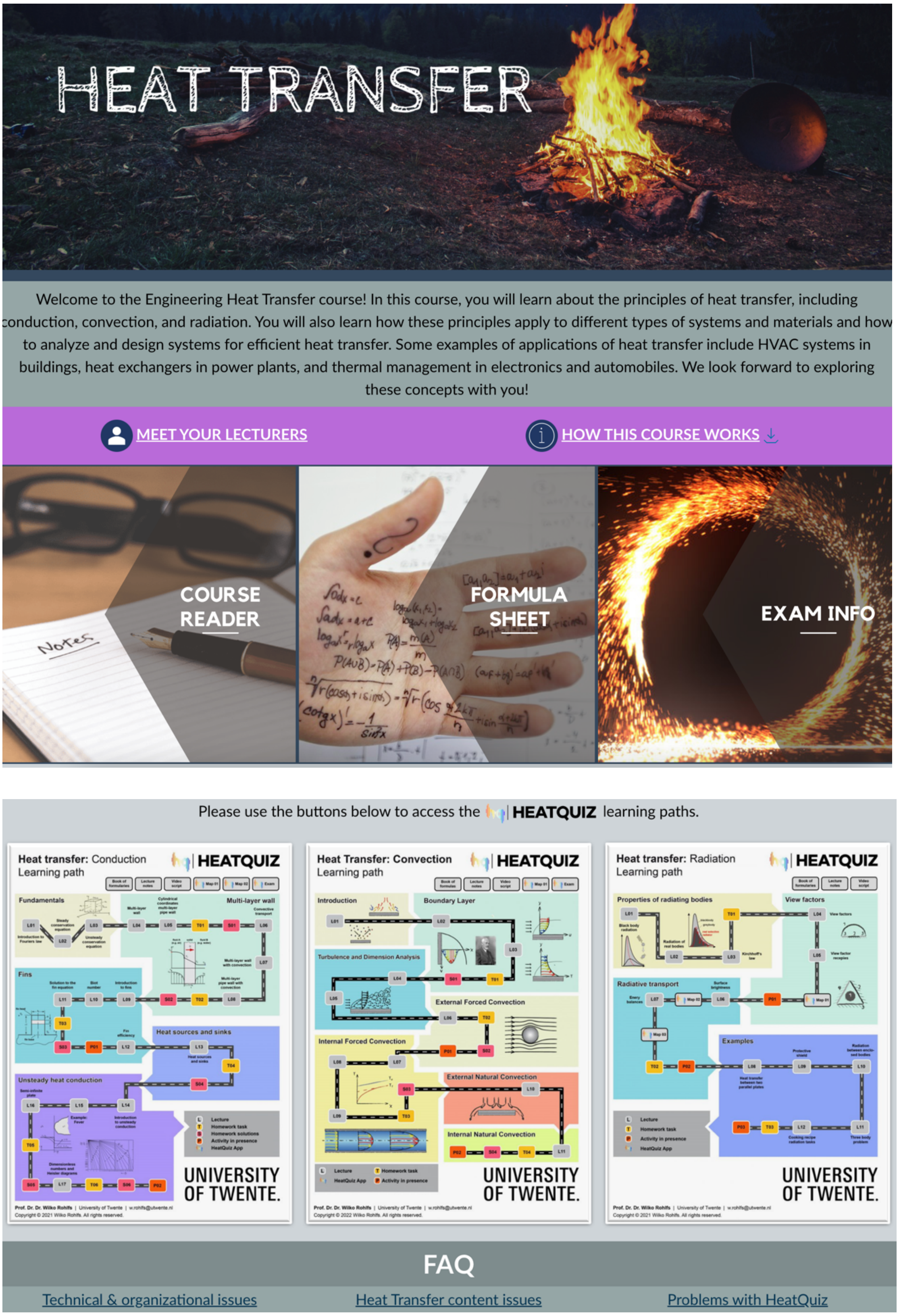
Activity integration	There is integration between the downloadable materials (i.e. course manual) and HeatQuiz
Cross-modality reinforcement	-

Table B4: HeatQuiz

HeatQuiz Codebook

Code	Element
Task prioritization	Learning paths are visually presented in a predetermined order to focus students on specific tasks or topics in a recommended order.
Concept structuring	Topics are presented in an organized and sequential format that supports a structured understanding of the concepts.
Comprehension checking	The quiz feature in HeatQuiz helps to assess comprehension.
Active engagement	Interactive quiz features like drawing temperature profiles stimulate engagement.
Reflective prompts	-
Predicting understanding	-
Estimating difficulty	-
Reviewing misunderstandings	-
Calibration reflection	-
Online resources	Micro-lectures and slides are included in the lessons.
Activity integration	-
Cross-modality reinforcement	Micro-lectures, slides, and quizzes are integrated into the lessons (seen in the pop-up menu).

Appendix C: Canvas Screenshots



Extra Heat Transfer Resit on 21st of August (approval by the examination board required)
WR · All sections
Dear students,We have received several requests for an extra resit in the Course Heat Transfer. To be eligible for this attempt, the examination board m...
Posted on: 12 Jul 2024, 12:29

May-21 exam with solutions.
JW · All sections
Dear Students, Please find a copy of the May-21 FM1 exam with solutions attached. Best regards,Jan, Lionel and KeesStromingsleer1TentamenHerkan...
Posted on: 28 Jun 2024, 15:26

Second Resit Fluid Mechanics 1
JW · All sections
Dear students, The second resit exam for Fluid Mechanics 1 will be planned on Friday the 5th of July, from 13:45 - 16:45. Best regards,Jan, Lionel and ...
Posted on: 18 Jun 2024, 09:52

Second Resit Fluid Mechanics 1
JW · All sections
Dear students, The second resit exam for Fluid Mechanics 1 will be planned in the week from 01-07 till 05-07.When the exact date and time are know...
Posted on: 14 Jun 2024, 15:32

Heat Transfer Resit Exam Review
DK · All sections
Dear students,On Wednesday the 19th of June, from 12:00-13:00, we will host the exam review in OH113.Please ensure punctuality, as the time allow...
Posted on: 8 Jun 2024, 11:49

Fluid Mechanics 1; Review of the resit exam
JW · All sections
Dear students, The review session for the resit exam for fluid mechanics 1 will be planned on Friday 07-06.In the schedule below you can see which of ...
Posted on: 31 May 2024, 11:45

Heat Transfer

RESOURCES
- Course Manual.pdf
- Reader.pdf
- Exercise Bundle.pdf
- Book of Formularies.pdf
- Solution Bundle.pdf
- Exam Bundle.pdf

HEATQUIZ
- HeatQuiz: Conduction
- HeatQuiz: Convection
- HeatQuiz: Radiation
- HeatQuiz: Mass Transfer

DISCUSSIONS
- Discussion on heat transfer issues (content)
- Discussion of technical and organizational issues (feedback on the reader)
- Discussion on problems with HeatQuiz

Pinned discussions

You currently have no pinned discussions
To pin a discussion to the top of the page, drag a discussion here, or select Pin from the discussion settings menu.

Discussions *Ordered by recent activity*

Discussion	Last post	Unread	Total
Discussion on heat transfer issues (content)	Last post at 21 May, 20:28	27	47
Discussion of technical and organizational issues (feedback on the reader)	Last post at 1 May, 18:42	0	16
Discussion on problems with HeatQuiz	Last post at 16 Mar, 18:46	9	23

Example Exams Heat Transfer

Find below a few exams for you to practice.

The knowledge that is required to solve the questions matches exactly the knowledge you gained (or will gain) with the learning paths of conduction, convection, and radiation.

For the exam, students received the book of formularies printed in a booklet format:

Book of Formularies.pdf

Practice Exam #1

Heat_Transfer_Practice_Exam_1.pdf

Heat_Transfer_Practice_Exam_1_Solutions.pdf

Practice Exam #2

Heat_Transfer_Practice_Exam_2.pdf

Heat_Transfer_Practice_Exam_2_Solutions.pdf

Practice Exam #3

Heat_Transfer_Practice_Exam_3.pdf

Heat_Transfer_Practice_Exam_3_Solutions.pdf

Exam 13.04.2022

Heat_Transfer_Exam_13_04_2022.pdf

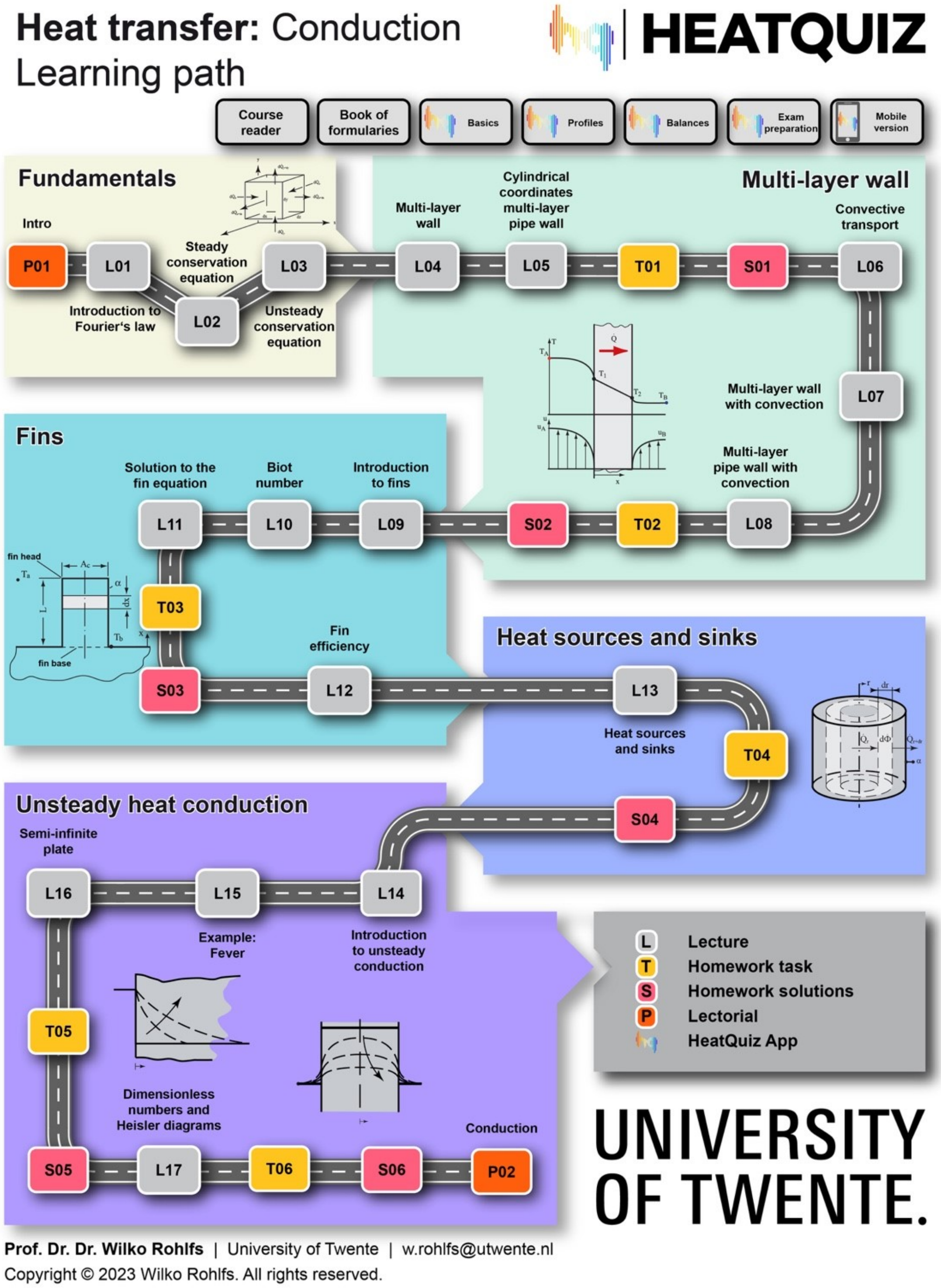
Heat_Transfer_Exam_13_04_2022_Solutions.pdf

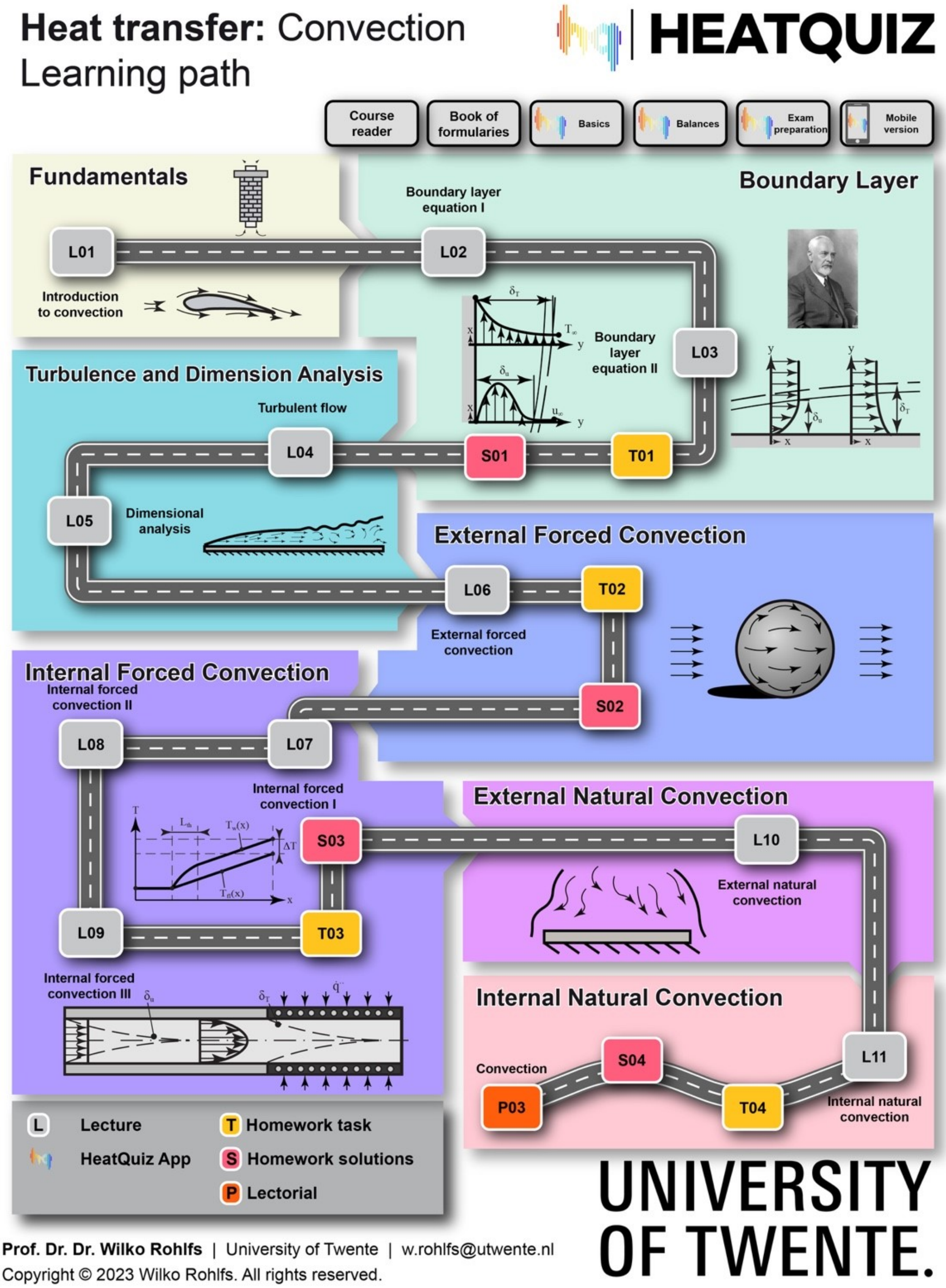
Exam 2023

HT_12042023.pdf

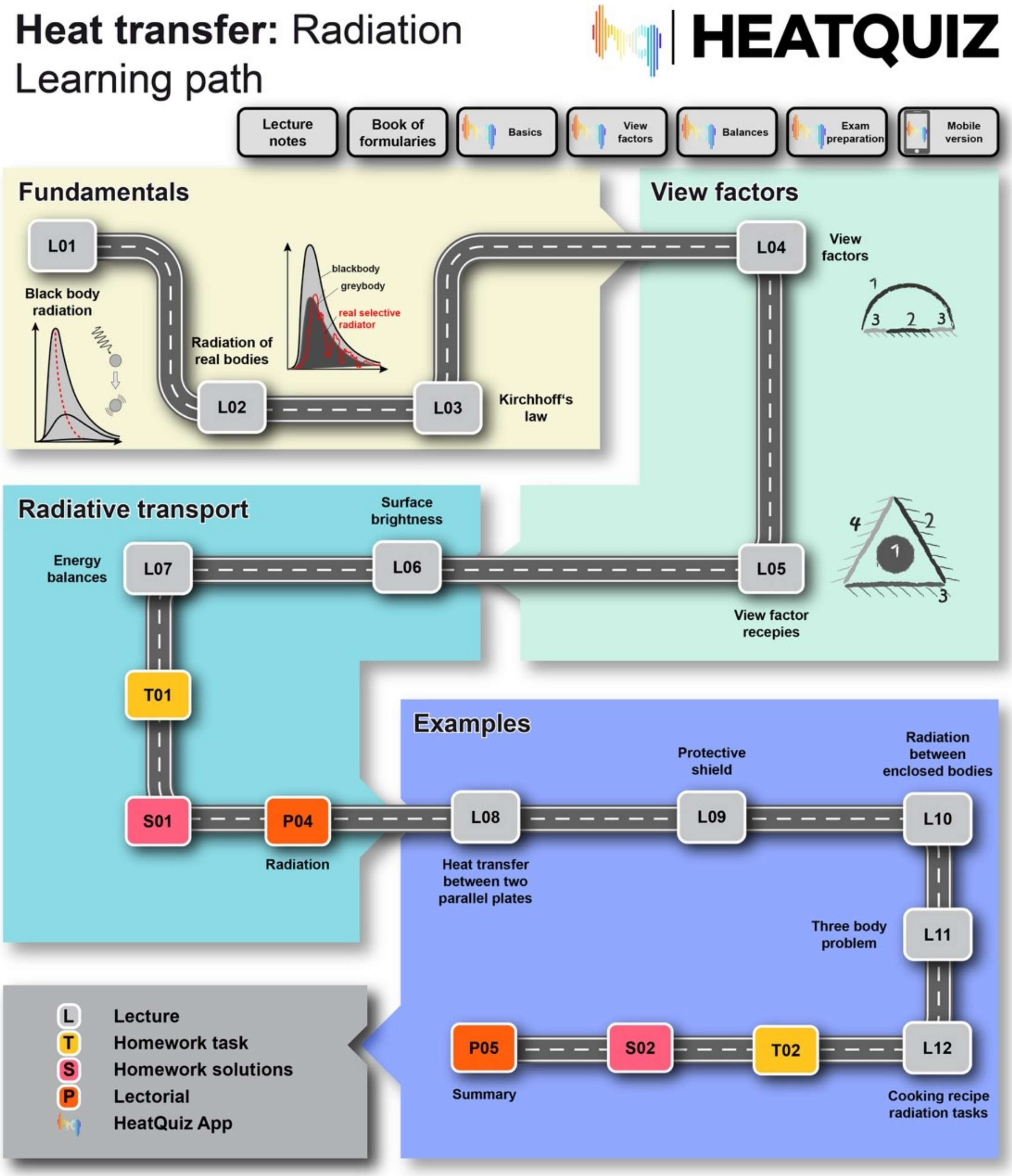
HT_12042023 Solutions.pdf

Appendix D: HeatQuiz Screenshots



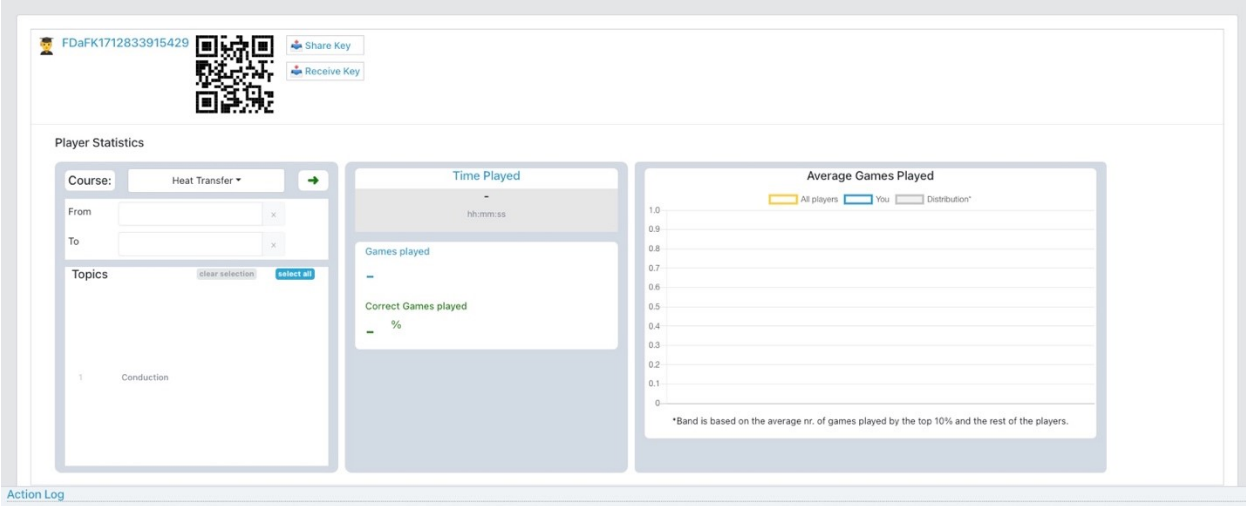


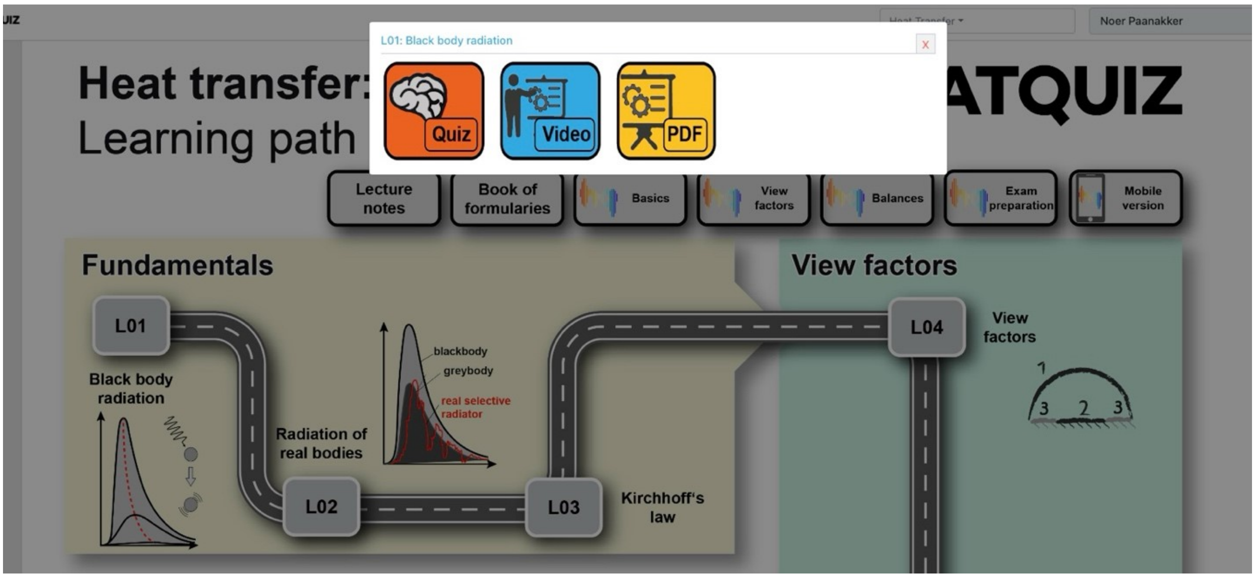
Prof. Dr. Dr. Wilko Rohlfs | University of Twente | w.rohlfs@utwente.nl



UNIVERSITY OF TWENTE.

Prof. Dr. Dr. Wilko Rohlfs | University of Twente | w.rohlfs@utwente.nl


FDaFK1712833915429
Share Key
Receive Key
Player Statistics
Course:
Heat Transfer
From
To
Topics
clear selection
select all
Conduction
Time Played
hh:mm:ss
Games played
Correct Games played
%
Average Games Played
All players
You
Distribution*
*Band is based on the average nr. of games played by the top 10% and the rest of the players.
Action Log


Noer Paanakker
L01: Black body radiation
Quiz
Video
PDF
Heat transfer:
Learning path
ATQUIZ
Lecture notes
Book of formularies
Basics
View factors
Balances
Exam preparation
Mobile version
Fundamentals
View factors
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L02
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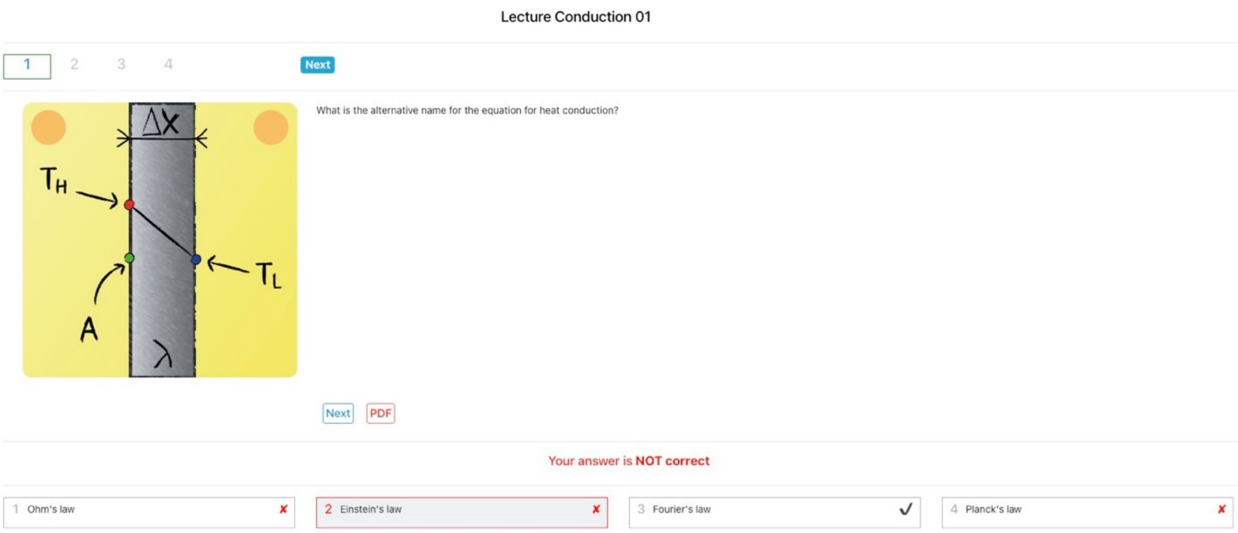
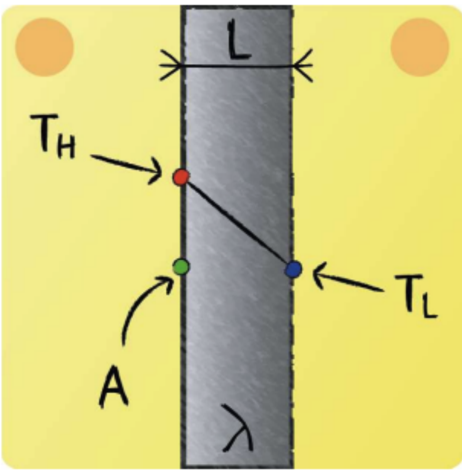
greybody
real selective radiator
L03
Kirchhoff's law
L04
View factors


Lecture Conduction 01
1
2
3
4
Next
What is the alternative name for the equation for heat conduction?
ΔX
T_H
T_L
A
λ
Next
PDF
Your answer is NOT correct
1 Ohm's law
2 Einstein's law
3 Fourier's law
4 Planck's law

Lecture 1 - Question 5

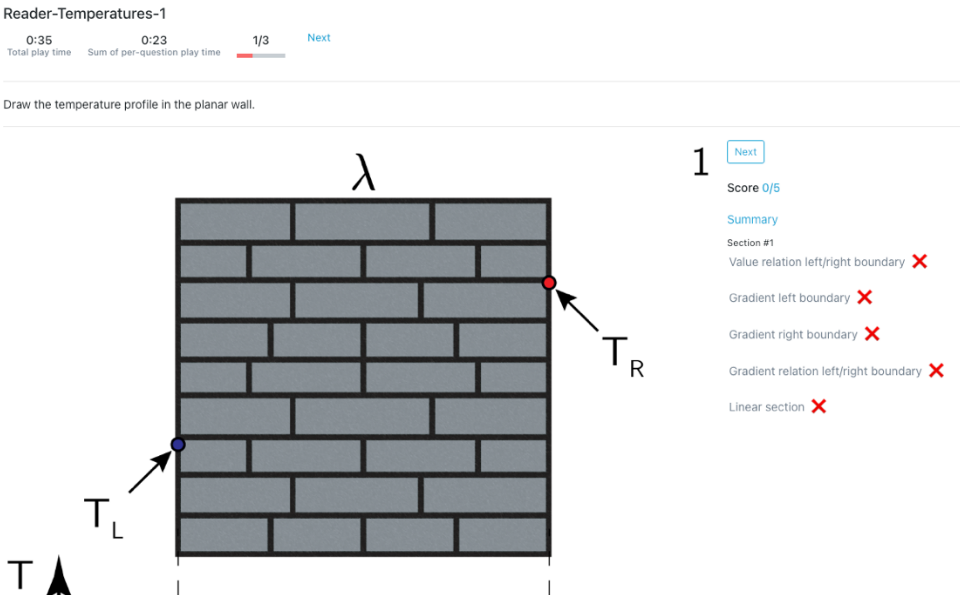


What is the alternative name for the equation for heat conduction?

The linear correlation between temperature gradient and area specific heat flux was discovered by Fourier in 1822 and consequently is refered to as Fourier's law. A general form is given by:

$$\dot{q}'' = -\lambda \frac{\partial T}{\partial n}$$

with $\frac{\partial T}{\partial n}$ representing the temperature gradient normal to a cross section of uniform temperature.



Appendix E: Course Manual

HEATQUIZ

Manual for the Heat Transfer Course

Course Setup

Welcome to "Heat Transfer," a fascinating course offered in Module 7 at the University of Twente. My name is Wilko Rohlfs, and as a professor specializing in Heat Transfer and Thermodynamics, I'm thrilled to guide you through this journey alongside my esteemed colleagues, Davoud Jafari and Nikki Basson, as well as our dedicated teaching assistants.

In this course, we will explore the three fundamental mechanisms of heat transfer: Conduction, Convection, and Radiation. Each of these mechanisms forms a distinct section of the course, providing a comprehensive understanding of how heat transfer operates in various contexts.

Our course structure adopts the flipped classroom model, offering a dynamic and interactive learning experience. You will have access to all essential course materials online, including readings, video lectures, and interactive resources. In addition to these materials, we will host five lecture sessions focusing on summarizing and synthesizing course content, rather than introducing new material.

We also have interactive exercise sessions where you'll see practical applications of heat transfer principles. These sessions are designed to enhance your understanding by demonstrating problem-solving techniques and providing opportunities for you to tackle similar tasks independently. Please note that while some exercise questions are exclusive to these sessions, they echo the tasks available online.

Our teaching assistants are readily available to assist you via the online FAQ, helping you navigate through the paper & pencil assignments that are crucial for your exam preparation. The reduced number of lectures and exercise sessions in comparison to other courses is intentional, allowing you ample time to engage with the provided reader, watch video lectures, and delve into the material at your own pace.

Stay updated with all course schedules and potential changes by regularly checking the rooster.

To maximize your learning experience, we recommend completing the assigned micro-lectures, quizzes, and homework from HeatQuiz before each lecture. This preparation enables you to participate actively in the exercise sessions, where you can seek clarification and delve deeper into specific assignments.

The course culminates in a written exam, where you'll have the opportunity to demonstrate your understanding of heat transfer principles and their applications.

We are excited to embark on this educational journey with you and look forward to a semester filled with discovery and growth in the field of Heat Transfer.

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HEATQUIZ

HeatQuiz

HeatQuiz is a platform with game-based elements for learning heat and mass transfer. During the course, three learning paths will be used which give you access to micro-lectures, quizzes, and homework tasks. You do not need to login to Canvas to have access. Depending on the screen resolution, the mobile or desktop version of the map may suit you better:

- Conduction: mobile / desktop
- Convection: mobile / desktop
- Radiation: mobile / desktop
- Exam preparation: mobile / desktop

When playing for the first time the message "Please add a key!" will appear. This has to be done by pressing the green button "Assign new key". A box will pop up in which a key has to be entered. This key should be your student number, e.g. s1234567.

Figure 1: Checking your student number and changing it if needed

For an optimal experience with HeatQuiz, please understand the following aspects of data storage and privacy:

1. **Local Storage of Data:** HeatQuiz primarily saves your progress data in your personal computer's cache. This implies that clearing your browser's cache, or using a different computer or browser, might result in the loss of your progress. We recommend using the same device and browser consistently to avoid this issue.
2. **Student Number for Progress Tracking:** To accurately track and record your progress, and to qualify for bonus points, it is crucial to enter your student number in the provided field. This allows us to effectively monitor your individual achievements.
3. **Data Transfer for Continuous Improvement:** HeatQuiz is configured to automatically transmit your responses to our server. This process is essential for us to continually refine HeatQuiz and enhance our educational programs. We assure you that protecting your privacy is a priority.
4. **Privacy and Anonymity:** The only personal information collected by HeatQuiz is the "map key" number you enter. If you prefer to remain anonymous, you may enter any random string of characters as your map key. This approach ensures your anonymity while allowing full participation in course activities.

By understanding and adhering to these guidelines, you can maximize your experience with HeatQuiz and help in the ongoing improvement of our educational tools, while maintaining control over your personal data and privacy.

On each map, you will have access to the **lecture notes**, and the **book of formulas**. At the start of each section in the lecture notes, the learning objectives and a series of comprehension questions related to each video are provided. We strongly recommend that you read the information provided before watching the videos. The different elements on the learning path are:

- The **L-blocks** denote a micro-lecture. Within this block, the video, lecture slides, and the corresponding quiz of that lecture can be found. We recommended to complete these little quizzes before attempting the more difficult T-block problems,
- The **T-blocks** denote homework tasks. These tasks increase in difficulty stepwise and work towards the level that is required for the exam.

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- The **P-blocks** denote points in time when a lectorial on that specific topic will be given on campus.

Learning strategy

1. **Choose Your Learning Format:** Begin by selecting your preferred method of learning for each topic. You can either read through the provided material or watch the corresponding micro-lecture. My personal suggestion is to print out the reading materials, which can help reduce digital distractions and aid in concentration.
2. **Set Your Learning Objectives:** Before diving into a movie or chapter, take a moment to review the learning goals and comprehension questions for that section. This pre-reading activity primes your brain to identify and retain key information.
3. **Engage with Interactive Tools:** After completing a section, tackle the associated HeatQuiz that accompanies the microlecture. This is an excellent way to reinforce what you've learned.
4. **Practice with T-tasks:** When you encounter T-tasks in your learning path, make it a point to solve them diligently. This will further enhance your understanding of the topic.
5. **Use the Book of Formularies:** Having a printed copy of the book of formularies is highly recommended. This practice will familiarize you with using this essential tool effectively.
6. **Utilize the FAQ Resource:** If you encounter difficulties, first try to find answers in the FAQ section before seeking out the solutions. Remember, finding the answer on your own is crucial for skill development.
7. **Review with Old Exams:** Upon completing the first topic (Conduction), take a look at past exams. This will not only help you gauge the difficulty level but also allow you to assess your preparedness.
8. **Prepare for the Exam:** Once you've mastered all three topics and completed all T-blocks, you're ready to start preparing for the exam. Print out the set of old exams available online for practice. Familiarize yourself with the format, which includes a question sheet and a designated solution form.
9. **Simulate Exam Conditions:** To get a realistic sense of the exam experience, attempt to complete the practice exams under exam-like conditions. Time yourself to gauge your efficiency and progress. As your skills improve, you'll notice a reduction in the time required to complete each exam.
10. **Review Your Answers Critically:** After completing an exam, compare your solutions with the provided answers. Avoid peeking at the solutions beforehand or attempting to solve problems solely in your head. Writing down your solutions is key to effective learning and self-assessment.

HEATQUIZ

Bonus points

During the course, you can earn up to 6 bonus points. You will receive six bonus points if you complete all the series of questions on the respective maps (2 points per map) with at least 75%. This can be done outside of the class sessions. Please see the timetable below for the deadlines.

Note, the bonus points will only be added to your grade if you have passed the course with a 5.5. The bonus points will be irrelevant for passing the exam.

The bonus point is valid for the entire year including the resit. If you write the exam next year, your bonus points from this year will be invalid. Obtaining all bonus points yields 6 additional points on top of the regular 60 points of the exam.

Procedures

For the dates of lectures, exercise sessions, and the corresponding homework, see the table below.

Schedule			
Week	**Date**	**Activity**	**Content**
1	07/02/2024	Lectorial 1	Introduction
Homework - Conduction: L01-L17, T01 - T06, Convection L01-L06, T01-T02			
2	-		
3	-		
4	-		
Deadline Bonus Point Conduction: 05.03.2024			
5	06/03/2024	Lectorial 2 Exercise session 1	Conduction Conduction T01-T06
Homework - Convection: L07–L11, T03-T04 **Deadline Bonus Point Convection: 12.03.2024**			
6	13/03/2024	Lectorial 3 Exercise session 2	Convection Convection T01-T04
Homework - Radiation: L01–L12, T01-T02			
7	-		
Deadline Bonus Point Radiation: 26.03.2024			
8	27/03/2024	Lectorial 4 Exercise session 3	Radiation Radiation T01-T02
9	04/04/2024	Lectorial 5 Exercise session 4	Exam preparation Exam preparation

Unfortunately, please be aware that the period between the on-site sessions is not equally distributed due to organizational reasons. We foresee that the one week for the topic of Convection (week 5/6) is insufficient for mastering the material. Consequently, we advise you to start with the topic of convection already in week 4. If any questions arise during the four-week break, please contact us via the FAQ or e-mail.

Lectorials
During each lecture, the topics of the micro-lectures will be discussed in depth. Furthermore, some discussion on that week's homework assignments will take place.

Exercise sessions
During the exercise sessions, problems related to that week's topic will be discussed classically, and the approach to tackling such problems will be explored. It is expected that students who join these sessions have worked on the homework that was given before to make them effective.

Homework
The homework from each week consists of watching the micro-lectures and solving the corresponding quizzes, which can be seen in the so-called L-blocks. Additionally, as preparation, students should solve the more complex tasks, which can be found in the T-blocks. The tasks in the T-blocks are ordered in such a way that the level of difficulty increases stepwise toward the level required for the exam. Thus, one should solve the tasks in the provided order to ensure an understanding of the content.

FAQ
Given the course's emphasis on independent work, questions about the content may naturally arise. In such instances, your peers could also benefit from viewing these questions and answers. To accommodate this, discussion pages are available on Canvas where you can post queries related to Heat Transfer content. Student assistants will actively monitor these pages and respond promptly. Therefore, do not hesitate to utilize this feature extensively rather than waiting for the next lecture or exercise session.

Organization

Teachers

- Prof. Dr.-Ing. Dr.rer.pol. Wilko Rohlfs (w.rohlfs@utwente.nl)
- Dr. Ir. Davoud Jafari (d.jafari@utwente.nl)
- Nikki Basson, MSc. (n.basson@utwente.nl)

Teaching Assistants

- Daan Kuiphuis (d.j.g.kuiphuis@student.utwente.nl) (contact in need of support in HeatQuiz)

Books for reference

1. Course reader provided online.

Appendix F: Course Reader

PART
I

Introduction to Heat Transfer

Learning goals:

- Conceptual understanding of the relation between heat transfer and thermodynamics.
- Conceptual understanding of the principles of energy transfer.
- Conceptual understanding of balances to solve engineering problems.

Comprehension questions:

- What is the relationship between thermodynamics and heat transfer?
- What are the mechanisms of heat transfer?
- How can energy balances be used to derive governing equations for heat transfer?
- What are some practical applications of heat transfer in engineering?

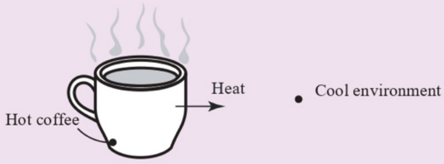
Section 1

Thermodynamics and heat transfer

Heat transfer, as a fundamental concept and sub-discipline of thermodynamics, plays a vital role in understanding the processes leading to thermal equilibrium. While classical thermodynamics primarily focuses on describing equilibrium states, heat transfer delves into the mechanisms and pathways that bring systems to this state. Unlike the concepts taught in the thermodynamics lectures before, which disregard time in the formulated equilibrium descriptions, heat transfer processes are intimately linked with the quantity of time. These processes occur due to spatial variations in thermodynamic potentials, specifically temperature differences, which drive heat flows and subsequently lead to temporal changes in temperature.

Phenomena 1.1

Consider preparing a cup of coffee or tea. According to the principles of thermodynamic equilibrium, the temperature of the beverage eventually reaches the same value as the room temperature. However, the time to reach the desired drinking temperature is a key focus of this course.



To understand this principle, recall the second law of thermodynamics. This law states that heat naturally moves from areas of higher temperature to those of lower temperature in a process called heat transfer. This phenomenon is attributed to the concept of entropy, which represents the tendency of systems to evolve towards a state of higher disorder. When the hot coffee comes into contact with the cooler environment, the kinetic energy of the high-energy molecules in the liquid is transferred to the lower-energy molecules in the environment, resulting in a more random distribution of energy and achieving a state of equilibrium.

Proficiency in describing heat transfer processes is indispensable for engineers across a wide range of scientific and engineering disciplines. In today's world, the miniaturization of electrical components is often constrained by the challenge of effectively dissipating heat. Electrical engines, power electronics, and batteries, which form the core components of an electrical drive train, heavily rely on efficient heat removal to ensure optimal performance and longevity. Additionally, the greenhouse effect and resulting climate change are consequences of the atmosphere's transmissivity to thermal radiation, which is dependent on CO_2 concentration. Advancements in home insulation and the implementation of modern heating systems, such as heat pumps, necessitate improved insulation materials or enhanced pathways for efficient heat transfer.

At the core, the description of heat transfer processes relies on the concept of balances, i.e. energy balances in conjunction with mass and momentum balances. Changes in the inner energy in time within a specified control volume are related to the energy flows across the system's boundaries. Describing the internal changes (transient processes) as well as the fluxes with the proper consecutive laws is an essential part of the heat transfer course. For the description of fluxes, the three basic mechanisms for the transportation of heat are conduction, convection, and radiation.

Subsection 1.1
Heat transfer mechanisms

Heat conduction is a fundamental mode of heat transfer that occurs through direct contact between substances on a molecular level, spanning not only solids but also liquids and gases. This process involves the transfer of thermal energy from regions of higher temperature to regions of lower temperature, driven by the exchange of kinetic energy between molecules. The rate of heat conduction depends on various factors, such as the temperature gradient, the thermal conductivity of the material, and the cross-sectional area available for heat flow. Efficient heat conductors, such as metals, exhibit high thermal conductivity, while insulators, like ceramics or nonmetals, have low conductivity, impeding the transfer of heat.

Figure 1.1. Conductive heat transport.

Phenomena 1.2

Imagine you have a metal spoon resting in a cup of hot soup. As you hold the handle of the spoon, you begin to feel the heat spreading throughout the handle.

In this example, the phenomenon of conduction is observed. Conduction is the transfer of heat energy through direct contact between objects that are at different temperatures. When you hold the metal spoon, the heat from the hot soup is conducted through the metal and transferred to your hand.

To better understand conduction, think of heat as the kinetic energy of molecules. In hot objects, these molecules move faster and have more energy. When the hot soup comes into contact with the metal spoon, the high-energy molecules collide with the cooler molecules in the spoon's handle and transfer some of their kinetic energy.

Heat convection is the transfer of heat energy from one point to another through the movement of a fluid or a gas. This transfer of energy occurs due to the movement of fluid or gas into a region of lower/higher temperature. Convection can occur in two ways: natural convection, which is driven by buoyancy forces due to temperature differences, and forced convection, which is driven by an external force such as a fan or a pump. Convection is an important mechanism of heat transfer in many engineering systems, from the cooling of engines to the design of heat exchangers.

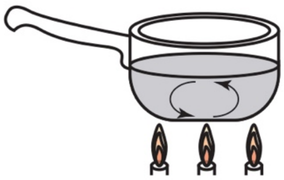


Figure 1.2. Convective heat transport.

Phenomena 1.3 Imagine you're riding your bicycle on a hot summer day. When you stop at a red light, you feel the heat around you intensify, creating an uncomfortable feeling. But as soon as you start moving at a slow speed, you feel cooler despite the physical effort of pedaling.

In this example, the transfer of heat from your body to the surrounding environment is influenced by the airflow created as you ride. When you're moving, the air rushes past your skin, taking away heat from your body and quickly moving away. This movement of air is called convection.

Convection is directly linked to the flow of fluids (like air or water). In this case, the movement of the air around you helps to cool your body down. The concept of convection shows a strong connection between the study of fluid mechanics and understanding heat transfer.

By studying both, fluid mechanics and heat transfer, you develop the ability to understand how air and other fluids move and how they affect the temperature of objects. This knowledge helps to design cooling systems, understand weather patterns, and improve understanding of how heat transfer behaves in different situations.

Radiation is the transfer of heat energy through electromagnetic waves, without the need for a material medium. This transfer of energy occurs due to the emission of electromagnetic waves by a hot object, which are absorbed by another object at a lower temperature. The rate of radiation is dependent on the temperature and emissivity of the objects involved, as well as the distance between them. Radiation is an important mechanism of heat transfer in many engineering systems, from the design of solar panels to the cooling of satellites.

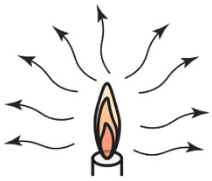


Figure 1.3. Radiative heat transport.

Phenomena 1.4 Imagine you are sitting outside on a sunny day, feeling the warmth of the sun on your skin. As the sun's rays reach the Earth's surface, they release energy in the form of electromagnetic waves, including infrared radiation. This process is known as radiative heat transfer.

Radiative heat transfer is the transfer of heat energy through electromagnetic waves without the need for any physical medium or direct contact. In this case, the sun acts as the heat source, and the energy is transferred from the sun to your body through the air.

To understand radiative heat transfer, consider that all objects above absolute zero temperature emit electromagnetic radiation in the form of photons. The hotter the object, the more intense the radiation is emitted. When the sun's rays reach your skin, they are absorbed, and the energy of the photons is transferred to your body's molecules, causing an increase in temperature and making you feel warm.

Unlike conduction and convection, which require physical contact or the movement of particles, radiative heat transfer can occur through a vacuum or any transparent medium, such as air or glass. This is why you can still feel the warmth of the sun on a clear day even though the space between the sun and the Earth is a near-vacuum.

Radiative heat transfer plays a crucial role in various natural and human-made processes. For example, the primary way the Earth receives energy from the sun is by radiation, which drives weather patterns and supports life on Earth. Similarly, radiative heat transfer is essential in designing and understanding heat exchange mechanisms in space, where conduction and convection are absent.

By studying radiative heat transfer, scientists and engineers can develop technologies that harness solar energy for power generation, and create more efficient heating and cooling systems.

SUBSECTION 1.2

Heat transfer mechanisms from molecular point of view

Heat transfer mechanisms, such as conduction and radiation, can be understood and explained at the molecular level.

Heat conduction from a molecular point of view:

At the molecular level, heat conduction occurs through the interaction between neighboring molecules. In a solid material, such as a metal, the atoms or molecules are closely packed and bonded together. When there is a temperature difference within the material, the molecules at the higher temperature have higher kinetic energy. These energetic molecules collide with their neighboring molecules, transferring a portion of their energy. During these collisions, the higher kinetic energy molecules impart some of their energy to the adjacent molecules with lower kinetic energy. This process continues throughout the material, creating a chain reaction of energy transfer. As a result, heat is conducted from the region of higher temperature to the region of lower temperature.

The ability of a material to conduct heat is determined by the molecular structure and bonding. Materials with closely packed atoms or molecules and strong intermolecular forces, such as metals, are efficient heat conductors. In contrast, materials with more loosely arranged molecules or weaker intermolecular forces, like insulators, impede the transfer of heat.

Heat radiation from a molecular point of view:

Heat radiation is the transfer of thermal energy through electromagnetic waves. Unlike conduction or convection, radiation does not require a material medium to propagate. Instead, radiative transport can occur in a vacuum or through transparent substances.

At the molecular level, heat radiation involves the emission and absorption of electromagnetic waves, specifically in the form of infrared radiation. Molecules have vibrating and rotating motions due to their thermal energy. These molecular motions result in the emission of electromagnetic waves, including infrared radiation.

When two objects are at different temperatures, the molecules in the hotter object have higher thermal energy, leading to more intense molecular vibrations and rotations. Consequently, these molecules emit a higher intensity of infrared radiation. The cooler object absorbs more radiation than it emits, causing the molecules to gain energy and increase their kinetic motion.

Heat radiation can also occur through reflection and transmission. Some materials can reflect a significant portion of incident radiation. Others, like transparent substances, allow radiation to pass through with minimal absorption, enabling heat transfer.

In summary, heat conduction involves the transfer of thermal energy through molecular collisions, whereas heat radiation occurs through the emission, absorption, reflection, and transmission of electromagnetic waves, particularly infrared radiation. Both processes contribute to the overall transfer of heat in different contexts and materials.

Section 2

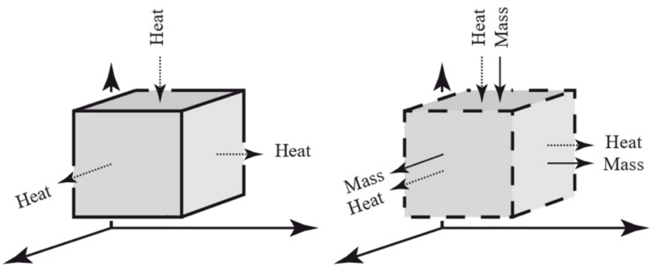
Systems and control volumes

A system refers to a specific amount of matter or a designated area in space that is selected for analysis. The region or mass located outside of the system is known as the surroundings. A boundary, either tangible or conceptual, separates the system from the surroundings. This boundary may be stationary or moveable, always representing the surface that connects the system to the surroundings. Worth noting that, from a mathematical standpoint, the boundary is considered to have zero thickness and cannot contain any mass or occupy any space in the surrounding area.

Depending on the selection of a specific mass or volume in space for examination, systems fall into either open or closed categories. A closed system contains a fixed quantity of mass and does not permit any matter to cross the boundary. Neither input nor output of mass is possible within a closed system, as depicted in Figure 2.1. However, energy can transfer in the form of work or heat across the boundary of a closed system, and the volume of a closed system does not have to be constant (imagine a helium balloon that rises into the sky, thereby expanding in volume but remains constant in mass).

An open system is a region in space that is deliberately chosen for analysis. This region typically encompasses a device that involves the flow of mass, such as a turbine, compressor, or nozzle. To examine the flow through these devices more effectively, the region within the device is commonly selected as the control volume. In an open system, both mass and energy can cross the boundary of the control volume, allowing for a more comprehensive analysis of the system's behavior.

A water bottle can exemplify open and closed systems. With the cap secure, the bottle is closed, barring fluid exchange. The liquid remains constant, isolating the interior. Removing the cap opens the system, allowing liquid exchange with the surroundings. This showcases how a water bottle shifts between open and closed, impacting matter and energy exchange across the system's boundaries.



(a) Closed system. (b) Open system.

Figure 2.1. Different control volumes and their boundaries.

Section 3

Balances

As an engineer, you likely learned about the concept of "balance" in your prior courses, such as mechanics (statics and dynamics). A balance is a versatile tool that applies to various situations, including mass, species, forces, or energy. When applied to dynamics, a balance can lead to an equation of motion.

To visualize the concept of energy balance, imagine a shoe box. Energy can flow in or out of the box through the defined boundaries. In subsequent chapters, you will learn more about how these energy flows can be described. Additionally, thermal energy can be generated inside the box, for example, by an electrical device that converts electric energy to thermal energy. All incoming and outgoing fluxes across the system boundaries, together with the heat sources/sinks inside the system, will affect the inner energy of the shoe box. If there is a positive net energy remaining in the box, the temperature inside increases, and if there is a negative net energy, the temperature will decrease.

Note, while considering one specific form of energy (heat), sources or sinks of this energy form can exist without violating the basic thermodynamic principle that energy in general cannot be created or destroyed.

Fundamental EQ

General energy balance:

$$\textbf{Temporal change in inner energy} = \textbf{ingoing fluxes} - \textbf{outgoing fluxes} + \textbf{sources} - \textbf{sinks}. \qquad (3.1)$$

The temporal change in inner energy $\frac{\partial U}{\partial t}$ may be linked to a change in temperature by $U = mcT$, with m denoting the system's mass, and c the specific heat capacity. The unit of this term is $\left(\frac{\mathrm{J}}{\mathrm{s}}\right)$ or (W). In analogy, all heat fluxes crossing the systems boundaries as well as the heat source and sinks need to be described in absolute values (W), rather than in area-specific $\left(\frac{\mathrm{W}}{\mathrm{m}^2}\right)$ or volume-specific $\left(\frac{\mathrm{W}}{\mathrm{m}^3}\right)$ quantities respectively. A system that does not change its inner energy in time is called a steady-state system.

Fundamental EQ

General energy balance steady-state system:

$$0 = \textbf{ingoing fluxes} - \textbf{outgoing fluxes} + \textbf{sources} - \textbf{sinks}. \qquad (3.2)$$

The opposite of a steady system is an unsteady system.

SUBSECTION 3.1

Systematic approach to solve engineering problems

In this textbook, we aim to teach you a systematic problem-solving approach in which the general structure is described as follows:

Approach 3.1

Solving complex problems by use of balances:

- For a chosen/defined control volume for the energy balance
  - Ensure that the chosen element is representative of the entire domain, as seen in the analysis of fluid flow through a pipeline. Consider a lengthy pipe through which fluid flows steadily. When modeling the fluid behavior, ensure the infinitesimal element is located within the fluid itself rather than the pipe wall.

1 Setting up the balance:

- Define changes in the internal energy.
  - The temporal change of fluid temperature over the course of time.
- Define fluxes across the boundaries.
  - Diffusive heat transfer due to temperature gradients.
  - Advective heat transfer due to fluid motion.
  - External mechanisms, such as radiative heat transport from the sun.
- Define internal heat sources and sinks.
  - Chemical reactor where the fluid flows through a reaction vessel.

2 Defining the elements within the balance:

- Define the fluxes based on constitutive laws for conduction, convection, and radiation.
  - Fourier's law of heat diffusion: $\dot{q}'' = -\lambda \frac{\partial T}{\partial x}$.
  - Newton's law of cooling: $\dot{q}'' = \alpha \left(T_{\mathrm{w}} - T_{\mathrm{f}}\right)$.
  - Stefan-Boltzmann Law: $\dot{q}'' = \sigma \epsilon T^4$.

3 Inserting and rearranging:

- Substitute all definitions and rewrite the differential equation in a clear manner.

4 Defining the boundary and/or initial conditions:

- Find the required conditions for solving the given differential equation.

5 Solving the equation:

- Using the boundary and initial conditions, find a mathematical expression for the required function.

Please be aware that several aspects mentioned in the provided approach have yet to be explored and may seem unexpected. The reader will explore these facets of heat transfer in the upcoming sections. The primary point to emphasize at this juncture is that a significant portion of the presented problems can be resolved by appropriately defining the domain and following the prescribed five steps.

By breaking down the problem into smaller steps, we can more easily analyze and understand the behavior of a system. This systematic approach is not only useful in heat transfer but also in many other fields of engineering and science. This approach allows us to tackle complex problems with better confidence and efficiency, leading to more effective and optimized designs.

An essential aspect of solving a differential equation is to apply the appropriate boundary or initial conditions that govern the behavior of the system being modeled. While this process may appear straightforward, errors occurring due to the complex nature of many differential equations are not uncommon. To minimize the potential for such errors, a systematic approach for determining the boundary or initial conditions necessary to solve the differential equation is recommended.

Approach 3.2

Finding the required boundary conditions:

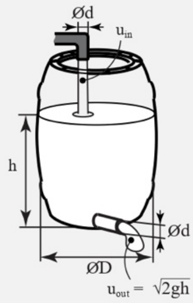
First, determine the number of conditions required to solve the equation. For partial differential equations, the number of initial and/or boundary conditions required depends on the number of independent variables and the order of the derivatives with respect to each variable.

For each required condition:

1. Is the temperature at the given location/beginning known?
   - If yes, state this condition.
   - If no, try step 2.
2. Are there symmetric or adiabatic conditions at the location/beginning?
   - If yes, state this condition.
   - If no, try step 3.
3. Is a heat transfer rate at the given location/beginning known?
   - If yes, derive this condition from a local energy balance.
   - If no, try a different location.

To illustrate the above-described systematic solution process, consider a fluid dynamic example that is solvable with a minor physics background.

Example 3.1 A fluid flows into the top of a barrel at a constant average velocity u_{in}. At the same time, a portion leaves the barrel through a pipe at a velocity u_{out}. Initially, the height of the fluid is equal to h_0. Find an expression for the height $h(t)$ of the fluid over time.



Hint:

- $u_{\text{in}} < u_{\text{out}}$.

1 Setting up the balance:

An incoming rate of mass from the tap is observed, while simultaneously, an outgoing mass flow due to the pipe at the bottom of the barrel is noted. If these rates are not identical, a temporal change of mass within the barrel will occur. Therefore, the mass balance is expressed as follows:

$$\frac{dm}{dt} = \dot{m}_{\text{in}} - \dot{m}_{\text{out}}.$$

Therein, the change in mass within the barrel is equal to the difference between the incoming and outgoing mass fluxes. Note, the dot above the m indicates that not the mass but the mass flux is considered.

2 Defining the elements within the balance:

Mass inside the barrel:

$$m = \rho V = \rho h(t)\frac{\pi D^2}{4}.$$

Incoming rate of mass:

$$\dot{m}_{\text{in}} = \rho u_{\text{in}} A_{\text{c}} = \rho u_{\text{in}} \frac{\pi d^2}{4}.$$

Outgoing rate of mass:

$$\dot{m}_{\text{out}} = \rho u_{\text{out}} \frac{\pi d^2}{4} = \rho\sqrt{2gh(t)}\frac{\pi d^2}{4}.$$

The concept of the outgoing mass flux is slightly more intricate because the pressure buildup in the barrel caused by the water level is considered. In fluid mechanics, you will discover that the velocity of the outflow has a square-root relationship with the water level. Important is to note that the water level, denoted as h, changes over time.

3 Inserting and rearranging:

$$\frac{dh}{dt} = \left(\frac{d}{D}\right)^2 \left(u_{\text{in}} - \sqrt{2gh(t)}\right).$$

4 Defining the boundary and/or initial conditions:

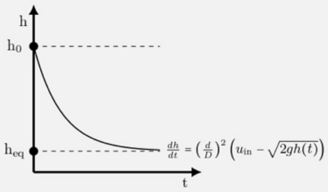
The height h has been differentiated once with respect to t and as such an initial water level (h) will be required to provide a solution to the problem.

Initially:

$$h(t = 0) = h_0.$$

5 Solving the equation:

Using an ODE solver, the following relationship is found:



Where at some point in time $u_{\text{in}} = u_{\text{out}}$ and the height of the fluid $h(t)$ reaches an equilibrium position which makes sense from a physical point of view.

Section 4

Important definitions and notations

Energy, also in the form of heat, is often measured in units such as Joules (J) or kilowatt-hours (kWh), depending on the context. Note, that energy is a scalar quantity without a direction.

On the other hand, the rate of energy is a vector quantity, which has both magnitude and direction. The rate of energy, also known as power P, refers to the amount of energy E transferred per unit of time Δt in units such as Jouler per seconds $\left(\frac{\mathrm{J}}{\mathrm{s}}\right)$, better known as Watts (W).

The heat transfer rate $\dot{Q}$, referring to the amount of heat Q transferred per unit of time Δt, is measured in the unit of Watts (W).

Definition

Rate of heat:

$$\dot{Q} = \frac{Q}{\Delta t} \;(\mathrm{W})\,. \tag{4.1}$$

Furthermore, the heat transfer rate $\dot{Q}$ per unit area A is called heat flux $\dot{q}''$ $\left(\frac{\mathrm{W}}{\mathrm{m}^2}\right)$. Thereby, area-specific values are denoted by two dashes $''$.

Definition

Heat flux:

$$\dot{q}'' = \frac{\dot{Q}}{A} \left(\frac{\mathrm{W}}{\mathrm{m}^2}\right). \tag{4.2}$$

Internal energy U is a system's total energy due to the particles' motion and interactions. The inner energy U of a system is directly proportional to both its mass m and specific enthalpy h. The internal energy is conserved in closed systems. Heat balances require accounting for changes in internal energy over time, along with external heat transfer and work done on the system, to describe the temperature distribution and behavior of a system.

Definition

Temporal change of inner energy:

$$\frac{\Delta U}{\Delta t} = m\frac{\Delta h}{\partial t} \approx mc\frac{\Delta T}{\Delta t} \;(\mathrm{W})\,. \tag{4.3}$$

Note: $h \approx cT$ at constant pressure p, constant specific heat capacity c and constant density ρ. A typical applicable case is water flow through a pipe.

Internal heat generation $\dot{\Phi}$ is a key factor to consider when modeling heat transfer problems. This parameter can significantly impact the temperature distribution and overall behavior of a system. This is important in fields such as nuclear engineering, where the heat generated by radioactive decay must be carefully accounted for in the design and operation of reactors. Similarly, in materials science, the heat generated by friction during manufacturing processes can affect the quality and performance of the final product. Thereby, the volume-specific heat generation $\dot{\Phi}'''$ $\left(\frac{\mathrm{W}}{\mathrm{m}^3}\right)$ is a result of the total heat generation $\dot{\Phi}$ and the systems volume V. Volume-specific values are denoted by three dashes $'''$.

Definition

Volum specific internal heat generation:

$$\dot{\Phi}''' = \frac{\dot{\Phi}}{V} \left(\frac{\mathrm{W}}{\mathrm{m}^3}\right). \tag{4.4}$$

Enthalpy flow, or advective transport, is another important concept in the study of heat transfer, representing the amount of energy transferred between a system and the surroundings as heat, with the addition of any work done by or on the system. Enthalpy flow is used for analyzing open systems, where energy transport due to mass transfer is of significance. The energy transported by the motion of mass $\dot{H}$ is directly proportional to the mass flow $\dot{m}$ and the specific enthalpy h.

Definition

Enthalpy flow:

$$\dot{H} = \dot{m}h = \dot{m}cT \ \ (\mathrm{W})\,. \tag{4.5}$$

To illustrate the difference between energy and power, consider the example of a light bulb. The energy consumed by a light bulb over a certain period, say an hour, is measured in kilowatt-hours. The power, or rate of energy consumption, of the light bulb is measured in watts or kilowatts. In this case, energy is the total amount of work that the light bulb consumed over time, while power is the rate at which work is performed.

In the context of heat transfer, energy balances are particularly important. An energy balance involves accounting for the inputs and outputs of thermal energy within a system. The goal is to ensure that the amount of energy entering the system is equal to the amount of energy leaving the system and that the energy within the system is conserved.

The principle of energy conservation, states that energy cannot be created or destroyed but can only be transformed from one form to another. The increase of inner energy in time of a control volume is the difference between the incoming and outflowing energy fluxes and the heat produced within the body.

Fundamental EQ

Law of conservation of energy for open systems:

$$\frac{dU}{dt} = \sum \dot{Q}_{\mathrm{in}} - \sum \dot{Q}_{\mathrm{out}} + \sum \dot{H}_{\mathrm{in}} - \sum \dot{H}_{\mathrm{out}} + \dot{\Phi}. \tag{4.6}$$

Fundamental EQ

Law of conservation of energy for closed systems:

$$\frac{dU}{dt} = \sum \dot{Q}_{\mathrm{in}} - \sum \dot{Q}_{\mathrm{out}} + \dot{\Phi}. \tag{4.7}$$

By applying this principle, governing equations for heat transfer that describe the behavior of thermal energy within a system can be derived.

One of the most important applications of energy balances in heat transfer is the development of the conduction equation. This equation describes the rate of heat transfer through a material by conduction and is derived by applying an energy balance to a small volume of material. The conduction equation allows the calculation of temperature profiles within a material as well as the heat transfer rate.

Example 4.1 A sphere with diameter d, density ρ, and specific heat capacity c_p, initially at temperature T_0, is subjected to a constant heat flux $\dot{q}''$. Heat losses are negligible, and the sphere's temperature is considered homogeneous. What is the sphere's temperature at time t_1?

1 **Setting up the balance:**

$$\frac{dU}{dt} = \dot{Q}_\mathrm{in} - \dot{Q}_\mathrm{out}.$$

2 **Defining the elements within the balance:**

Internal energy:

$$U = mc_\mathrm{p}T(t) = \rho\frac{\pi d^3}{6}c_\mathrm{p}T(t).$$

Rate of heat transferred to the sphere:

$$\dot{Q}_\mathrm{in} = \dot{q}''A_\mathrm{s} = \dot{q}''\pi d^2.$$

Rate of heat loss from the sphere:

$$\dot{Q}_\mathrm{out} = 0.$$

3 **Inserting and rearranging:**

$$\frac{dT}{dt} = \frac{6\dot{q}''}{\rho c_\mathrm{p} d}.$$

4 **Defining the boundary and/or initial conditions:**

The temperature T has been differentiated once with respect to t. To solve the differential equation, one initial condition is required.

Initially at $t = 0$:

$$T(t = 0) = T_0.$$

5 Solving the equation:

Integration yields:

$$T(t) = \frac{6\dot{q}''}{\rho c_p d} t + c_1.$$

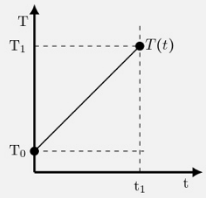
The initial condition yields that $c_1 = T_0$

Which gives the temperature function over the course of time:

$$T(t) = \frac{6\dot{q}''}{\rho c_p d} t + T_0.$$

Thus, the sphere's temperature at t_1 equals:

$$T(t_1) = \frac{6\dot{q}''}{\rho c_p d} t_1 + T_0.$$



Appendix G: Ethics Approval Request Form

UNIVERSITY OF TWENTE.

FACULTY BMS

240421 REQUEST FOR ETHICAL REVIEW

Request nr: 240421

Researcher: Dasgupta, C.

Supervisor: -

Reviewer: Farrokhnia, M.

Status: Approved by commission

Version: 2

1. START

A. TITLE AND CONTEXT OF THE RESEARCH PROJECT

1. What is the title of the research project? (max. 100 characters)

Fostering self-regulated learning using the HeatQuiz app

2. In which context will you conduct this research?

Academic research conducted by a faculty member

3. Date of the application

02-07-2024

5. Is this research project closely connected to a research project previously assessed by the BMS Ethics Committee?

No/Unknown

B. CONTACT INFORMATION

6. Contact information for the lead researcher

6a. Initials:

C.

6b. Surname:

Dasgupta

6c. Education/Department (if applicable):

BMS-IST

6d. Staff or Student number:

77186380

6e. Email address:

c.dasgupta@utwente.nl

6f. Telephone number (during the research project):

+31534899372

6g. If additional researchers (students and/or staff) will be involved in carrying out this research, please name them:

Prof.Dr.-Ing. Wilko Rohlfs (w.rohlfs@utwente.nl), Dr. Sebastian Dennerlein (s.dennerlein@utwente.nl), Dr. Pascal Wilhelm (p.wilhelm@utwente.nl), MSc Nick Goossen (n.goossen@utwente.nl), Noer M.G. Paanakker (n.m.g.paanakker@student.utwente.nl)

6h. Have you completed a PhD degree?

Yes

8. Is one of the ethics committee reviewers involved in your research? Note: not everyone is a reviewer.

No

C. RESEARCH PROJECT DESCRIPTION

9a. Please provide a brief description (150 words max.) of the background and aim(s) of your research project in non-expert language.

The course Heat Transfer with around 250 students every year offers self-study materials within the Bachelor program using the in-house developed online learning platform - HeatQuiz. It offers vairous digital learning activities like videos, homework tasks and quizzes on a visualized linear learning path. Recently, the platform has been adopted by multiple larger core-courses of different study programs at the UT and other universities. However, because of the high degree of freedom, many students face issues with motivation and time management. While excellent learning material has been developed in HeatQuiz, these do not support students' self-regulation in terms of planning, monitoring and assessing learning goals, and promote teachers' understanding of student progress and self-regulation behvaiour. The goal of the project is to identify, develop and implement pedagogical methods and procedures to enable a transition from unsupervised to supervised and guided self-regulated learning of students (and learner-centered teaching).

9b. Approximate starting date/end date of data collection:

Starting date: 2024-07-16

End date: 2026-11-14

9c. If applicable: indicate which external organization(s) has/have commissioned and/or provided funding for your research.

Commissioning organization(s):

Not applicable

Funding organization(s):

University of Twente - 4TU CEE

Grant number:

NA

2. TYPE OF STUDY

Please select the type of study you plan to conduct:

My study will involve both existing and new data.

3. RESEARCH INVOLVING EXISTING DATA OR DOCUMENTS

A. WHICH DATA AND/OR DOCUMENTS WILL BE ACCESSED AND HOW?

10. Please provide a brief description of the data or documents that you plan to use (max. 2000 characters, including spaces).

We have HeatQuiz app log data from students who took the course in previous years. This data is already anonymized via the app (using an unique identifier) and available on secured UT servers. The existing data does not contain any identifiable information.

11. Please indicate whether the data/documents you will use are:

- Private

11d. Please indicate the purpose for which these data were originally collected (max. 2000 characters, including spaces):

The log data through the HeatQuiz learning platform is automatically collected to understand students' use and gather usability statistics (e.g., how much time they spend on a topic/resource etc.).

11e. How will you obtain access to these private data, and what are the conditions for use?

Wilko has developed the HeatQuiz learning platform and also coordinates/teaches multiple courses where this app is used. Thus, he already has access to the log data. Wilko is the PI of this research study and he can provide the researchers (mentioned previously in this ethics form) access to the existing data. The existing data is already anonymized. It can be used to understand students' existing usage and learning preferences with HeatQuiz in previous years to inform the design of scaffolds for supporting self-regulated learning.

11f. Have the individuals/organizations to whom these data pertain provided consent for additional, later use of the data?

No

B. CONFIDENTIALITY AND ANONYMITY

12. Does the dataset contain information (or a combination of information) that can be traced back to specific individuals/organizations?

No

4. RESEARCH INVOLVING THE COLLECTION OF NEW DATA

A: RESEARCH POPULATION

20. Please provide a brief description of the intended research population(s):

Research participants include students, facilitators, and teachers of ongoing courses in multiple UT Bachelor programs of Mechanical Engineering, Industrial Design Engineering, and Biomedical Engineering at University of Twente such as Statics, Dynamics, Thermodynamics, Elasticity Theory, and Fluid Mechanics. These courses run for 8-10 weeks, with 7-8 face-to-face meetings of 1.5h each (1 introductory session, 3 lectures on conduction, convection, and radiation, one exercise for each lecture, and an exam preparation session). The students are expected to study in total 87.5-105h (3.5 ECTs). 10-20% should be spent on solving questions using the HeatQuiz app.

21. How many individuals will be involved in your research?

Approximately 250 students enrolled in the bachelors programme and the facilitators of the courses will be involved in this research each year of the project.

22. Which characteristics must participants/sources possess in order to be included in your research?

There are no exclusion criteria. Since this is part of the regular teaching, students signed up for the course automatically become eligible for participating in this project. Every student will be provided with the research information including the data to be collected for research purposes. Participation is voluntary and students can opt-out of the study. Students who do not wish to participate in this research can still use the HeatQuiz app but their data will not be analyzed. All data collected through the HeatQuiz app gets anonymized automatically. The anonymization process is facilitated by automatically assigning unique codes to the student when they begin using the HeatQuiz app (students continue using the same code in further sessions with HeatQuiz). Individual learning trajectories can be tracked via these unique codes.

23. Does this research specifically target minors (<16 years), people with cognitive impairments, people under institutional care (e.g. hospitals, nursing homes, prisons), specific ethnic groups, people in another country or any other special group that may be more vulnerable than the general population?

No

24. Are you planning to recruit participants for your research through the BMS test subject pool, SONA

No

B. METHODS OF DATA COLLECTION

25. What is the best description of your research?

- (Online) survey research

- Observation research
  - By researcher in person
  - By photo, video or audio recording
- Experimental/intervention research
- Interview research
- Research using focus groups and/or stakeholder workshops

26. Please prove a brief yet sufficiently detailed overview of activities, as you would in the Procedure section of your thesis or paper. Among other things, please provide information about the information given to your research population, the manipulations (if applicable), the measures you use (at construct level), etc. in a way that is understandable for a relative lay person.

All participants will receive content relevant to the course they are enrolled in via the HeatQuiz app (https://heatquiz.wsa.rwth-aachen.de/). They will engage in real life learning activities as part of their regular learning process by using digital diary (including questionnaires) and dashboard to track their progress in the course. Project-specific activities that participants will engage in includes all Design Based Research activities of exploration and analysis phase (e.g., interviews and obervations) and evaluation and implementation (e.g., feedback in co-design like alpha and beta testing of prototypes, but also additional questionnaire and interviews at the end). First, the students are informed about the course objectives, broad aims of the research study, and the opt-out process. Second, they will be introduced to the HeatQuiz app and the digital diary. Third, students will use the app and engage with the course content and record their reflection on a weekly basis. Every student will be automatically assigned an unique identifier/code by the app to preserve their anonymity. This identifier will be used to map the saved log data from the app and the information entered in the digital diary. A dashboard will be provided to the students after co-designing and testing this with the students. For gathering feedback on the design of this dashboard, student interviews/focus group sessions are likely to be conducted at multiple points in the course. We will take utmost care to ensure that these sessions do not disrupt the students' learning experience and become a burden for them. Anonymity during these sessions will be ensured by using only audio recording that will be transcribed immediately and mapped using the unique identifier. We will not collect any personal identifiable information during these sessions. The digital diary responses and log data from the HeatQuiz app will be used to analyze students' evolution along various SSRL metrics - monitoring, regulating, self-asessing, etc.

How much time will each participant spend (mention the number of sessions/meetings in which they will participate and the time per session/meeting)?

The course runs for 8-10 weeks, with 7-8 face-to-face meetings of 1.5h each (1 introductory session, 3 lectures on conduction, convection, and radiation, one exercise for each lecture, and an exam preparation session). The students are expected to study in total 87.5-105h (3.5 ECTs). 10-20% should be spent on solving questions using the app. The rest is video lectures, reading readers, solving paper and pen questions, and solving old exams. They will also spend around 20-30 min using the digital diary. For the duration of the course, we will conduct 2-3 rounds of interviews/focus groups lasting 20-30 min each.

C: BURDEN AND RISKS OF PARTICIPATION

27. Please provide a brief description of these burdens and/or risks and how you plan to minimize them:

There are no foreseeable risks in this study. To minimize the potential for discomfort and burden, data collection activities that require additional time (e.g., interviews) will be done at a time convenient for the participants. Such activities will also be conducted discreetly in separate safe spaces. If participants experience any burden or discomfort from the project-specific activities mentioned previously then we will remind them that their participation is voluntary and they can choose to withdraw their consent without any consequence. We will monitor for such cases by enabling students to self-report their discomfort to a member from the research team who is not their instructor.

28. Can the participants benefit from the research and/or their participation in any way?

Yes

Please Explain:

Participants may potentially benefit from the study by learning effective self-regulation skills and become more reflective in their problem-solving process. They may also experience more agency by having a voice in refining the intervention designed for them. Additionally, students may benefit from more learner-centered teaching by teachers receiving insights on formative assessment on class level.

29. Will the study expose the researcher to any risks (e.g. when collecting data in potentially dangerous environments or through dangerous activities, when dealing with sensitive or distressing topics, or when working in a setting that may pose ‘lone worker’ risks)?

No

D. INFORMED CONSENT

30. Will you inform potential research participants (and/or their legal repsentative(s), in case of non-competent participants) about the aims, activities, burdens and risks of the research before they decide whether to take part in the research?

Yes

Briefly clarify how:

All participants will be provided with the research information sheet and the opt-out process at the beginning of the research study. These documents outline the aims, activities, burdens and risks of the research.

32. How will you obtain the voluntary, informed consent of the research participants (or their legal repsentatives in case of non-competent participants)?

Passive/tacit consent

Please provide a brief explanation of why you think passive consent is acceptable and how sufficient action will be taken to inform the participants or their legal repsentatives

-

33. Will you clearly inform research participants that they can withdraw from the research at any time without explanation/justification?

Yes

34. Are the research participants somehow dependent on or in a subordinate position to the researcher(s) (e.g. students or relatives)?

Yes

If yes how will you ensure that these participants have voluntarily consented to take part in the research?

To ensure anonymity, names of participants are replaced with a unique code by the HeatQuiz app when they log into the app. To ensure and enable voluntary consent, students will be instructed to email me (Chandan), a non-instructor of the courses where the research will take place, so that the course instructor is not aware of the opt-out before the end of the grading process. Thus, students' anonymity is preserved even if they opt-out and every student (irrespective of their participation status in the study) can be treated fairly by the instructor.

35. Will participants receive any rewards, incentives or payments for participating in the research?

- No

36. In the interest of transparency, it is a good practice to inform participants about what will happen after their participation is completed. How will you inform participants about what will happen after their participation is concluded?

- Participants will receive the researcher’s contact details, so that they can contact the researcher if they have questions/would like to know more.
- Participants will receive oral/written information about what the researcher(s) will do with the collected data.

E. CONFIDENTIALITY AND ANONYMITY

37. Does the data collected contain personal identifiable information that can be traced back to specific individuals/organizations?

No

39. Will you make use of audio or video recording?

Yes

- What steps have you taken to ensure safe audio/video data storage?

  We will only collect audio data. No personal identifiable information will be asked/recorded. The audio data will be transcribed immediately, anonymized, and saved on secured Twente servers.

- At what point in the research will tapes/digital recordings/files be destroyed?

  The audio files will be destroyed at the conclusion of this research study.

5. DATA MANAGEMENT

- I have read the UT Data policy.
- I am aware of my responsibilities for the proper handling of data, regarding working with personal data, storage of data, sharing and presentation/publication of data.

6. OTHER POTENTIAL ETHICAL ISSUES/CONFLICTS OF INTEREST

40. Do you anticipate any other ethical issues/conflicts of interest in your research project that have not been previously noted in this application? Please state any issues and explain how you propose to deal with them. Additionally, if known indicate the purpose your results have (i.e. the results are used for e.g. policy, management, strategic or societal purposes).

There are no ethical issues/conflicts foreseeable in this project.

7. ATTACHMENTS

Information Sheet.pdf

8. COMMENTS

Dasgupta, C. (16-07-2024 14:47):

This is so strange. The text for #32 keeps on getting erased somehow. This is the second time this is happening. I have updated the text again. Hoping it remains saved till it reaches you :D. Here is what I added for #32 - "We select the opt-out process for seeking consent because this is the established model for using HeatQuiz in the courses where this research will be conducted. So students are already familiar with this process. We will take special care to inform participants of the study and the possibility to opt out. The opt-out procedure is straightforward and can be done anytime during the course. For opting out, students have to email me (Chandan), a non-instructor of the course(s) where the research will take place, so that the course instructor is not aware of the opt-out before the end of the grading process. This opt-out process will be specified in the information sheet that will be provided to the students when the course begins."

- Chandan

Farrokhnia, M. (16-07-2024 10:23):

Dear Chandan, Thank you for the changes you made to your response to query 34. It is now clearer to me how you are going to deal with that potential situation. However, I think you forgot to update your response to query 32. Would you please kindly check that as well? Best regards, Reza

Dasgupta, C. (16-07-2024 07:18):

Dear Reza - Thank you for reviewing the application quickly and sharing the thoughtful comments. I have updated #32 and #34 to address the concerns. Kindly let me know if you have any further comments.

Best,

Chandan

Farrokhnia, M. (15-07-2024 10:12):

Dear Chandan, thank you for providing such a thorough description of your interesting study. I do not have any major concerns regarding its ethics, but I would appreciate further elaboration on some of your responses to queries.

- In particular, in response to query 32, you mentioned that you will use a "Passive/tacit consent" form for enlisting your research participants. Based on what you explained later, it seems that you will use an active consent form rather than passive. If this is not correct, I would appreciate it if you could explain the reason for this decision when responding to query 32.
- In addition, in response to query 34, you mentioned that the research participants are dependent on the researchers (perhaps since some of them are their teachers). Although making the responses anonymous would assure students that their participation will not affect, for instance, their final grade, I can imagine there might still be students who do not want to participate in the study but are afraid to say so because they might think teachers would react negatively. In this situation, how will you ensure that students feel completely free to decide whether or not to participate without any fear of repercussions?

Thank you for your attention to these matters. Reza

9. CONCLUSION

Status: Approved by commission

The BMS ethical committee / Domain Humanities & Social Sciences has assessed the ethical aspects of your research project. On the basis of the information you provided, the committee does not have any ethical concerns regarding this research project. It is your responsibility to ensure that the research is carried out in line with the information provided in the application you submitted for ethical review. If you make changes to the proposal that affect the approach to research on humans, you must resubmit the changed project or grant agreement to the ethical committee with these changes highlighted.

Moreover, novel ethical issues may emerge while carrying out your research. It is important that you re-consider and discuss the ethical aspects and implications of your research regularly, and that you proceed as a responsible scientist.

Finally, your research is subject to regulations such as the EU General Data Protection Regulation (GDPR), the Code of Conduct for the use of personal data in Scientific Research by VSNU (the Association of Universities in the Netherlands), further codes of conduct that are applicable in your field, and the obligation to report a security incident (data breach or otherwise) at the UT.

Attachment: Information Sheet.pdf

Information Sheet

The purpose of this research is to understand how students use an online learning platform and engage in self-study using given course materials.

There are no risks associated with this research and this research project has been reviewed and approved by the BMS Ethics Committee. Participation may help students gain relevant knowledge and skills for managing their self-study process.

Participation in this project is voluntary and does not affect classroom activities or your grades. If you would like to withdraw from the study at any point, please send an email to Chandan (information listed below) and mention that you would like to opt out (no reasons are required).

During the research no personal information will be collected. The researchers mentioned below will observe the class and conduct interviews to learn from your experience of the learning platform. During such observations and interview process, the researchers may audio record you. These audio recordings will be strictly confidential, available only to the research personnels, and used only for transcribing the conversation for further analysis. The recordings will be deleted at the conclusion of the study (end of 2026). Personal details will not be collected. If any personal detail is collected by mistake, then it will be anonymized immediately.

If you have any concerns regarding this research, you may contact the researchers below or email the BMS Ethics Committee.

Researchers:

Dr. Chandan Dasgupta - c.dasgupta@utwente.nl
Prof.Dr.-Ing. Wilko Rohlfs - w.rohlfs@utwente.nl
Dr. Sebastian Dennerlein - s.dennerlein@utwente.nl
Dr. Pascal Wilhelm - p.wilhelm@utwente.nl
MSc Nick Goossen - n.goossen@utwente.nl
Noer M.G. Paanakker - n.m.g.paanakker@student.utwente.nl

Contact Information for Questions about Your Rights as a Research Participant

If you have questions about your rights as a research participant, or wish to obtain information, ask questions, or discuss any concerns about this study with someone other than the researcher(s), please contact the Secretary of the Ethics Committee/domain Humanities & Social Sciences of the Faculty of Behavioural, Management and Social Sciences at the University of Twente by ethicscommittee-hss@utwente.nl

UNIVERSITY OF TWENTE.

Appendix H: Informed Consent Form

Information Sheet

"Study Habits in the Heat Transfer Course"

Purpose of the research

This study investigates how learners within the Heat Transfer course at the University of Twente, Vrije Universiteit Amsterdam, and RWTH Aachen University engage with the HeatQuiz platform and manage their learning processes. The goal is to better understand their study habits and identify potential solutions, such as developing a learning analytics dashboard (LAD), to support students in monitoring their progress and improving their learning outcomes.

Benefits and risks of participating

By participating in this study, you will contribute to developing a tool that may enhance the learning experience for future students. Teachers and TAs may also benefit from improved resources and insight into how students interact with the course material to better tailor their teaching strategies. Additionally, this research study was approved by the BMS ethics committee and poses no physical or mental risks of participating. However, you may be asked to reflect on learning challenges that may evoke frustration.

Procedures for withdrawal from the study

You have the right to withdraw from the study at any point, without giving a reason. If you choose to withdraw, any data you have provided will be excluded from further analysis, provided you make the request before the data is anonymized. After anonymization, withdrawal of data may not be possible as it will be impossible to trace the data to individual identities. If you wish to withdraw, please contact the researcher, and your participation will be discontinued immediately.

Data collection

The data will be collected through semi-structured interviews, focusing on your experience with the Heat Transfer course and student study habits. With your consent, interviews will be audio-recorded, transcribed, and analysed. Only relevant researchers will have access to your data, which will be securely stored and anonymized before analysis.

You will always have the right to:

- Request access to the data collected from you.
- Rectify any personal data that you believe to be incorrect.
- Request the erasure of your personal data at any time before anonymization.

Data anonymization process

The interview and data collection process will be fully anonymized to focus on student experiences rather than individual identities. Here's how it works:

1. Participate in the audio-recorded interview
2. The audio recording will be transcribed
3. The original audio recording will be deleted.
4. The transcription will be completely anonymized.
    a. The file is renamed (e.g., "Student_1")
    b. All personal information in the transcript is replaced with "X."
    c. Metadata is anonymized
5. Calendar appointments, emails, and other communications will be deleted.

This data will be managed on the main researcher's laptop. Once anonymization is complete, the transcription will be uploaded to the research team's password-protected systems. This ensures that your input remains disconnected from your identity.

Data usage

Data will be used to analyse students' study habits in the Heat Transfer course to understand the effectiveness of the HeatQuiz platform and the educational format of the Heat Transfer course. These insights will inform the design of a student support tool. All data will be anonymized to ensure that personal identifiers (e.g., names, student IDs) are removed. Data will be analysed without directly linking it to you. Only the research team members will have access to the (anonymized) data, which will be stored securely in password-protected systems.

Anonymized data may be archived for future research purposes. Should this occur, it can never be linked to your identity. The anonymized data may be used in part of a publication in scientific journals, presented at conferences, or included in reports.

Retention period for the research data

The research data will be retained for a period of 10 years following the conclusion of the study to allow for potential publication and review. After this period, all data will be deleted. The retention period may be extended if the anonymized data is deemed valuable for future studies.

Contact Information

If you have any questions or concerns about the study, your participation, or how your data will be used, you can contact the researcher and/or the BMS Ethics Committee:

Researcher: Noer Paanakker, n.m.g.paanakker@student.utwente.nl

BMS Ethics Committee/domain Humanities & Social Sciences: ethicscommittee-hss@utwente.nl

Consent Form for "Study Habits in Heat Transfer Course“

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information sheet, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	□	□
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions. I can withdraw from the study at any time, without having to give a reason.	□	□
I understand that taking part in the study involves audio-recorded interviews that will serve to document my experiences of the Heat Transfer course.	□	□
Use of the information in the study		
I understand that the information I provide will be used to inform the development of an educational intervention that will improve the quality of the Heat Transfer course.	□	□
I understand that the information I provide can be used to help shape a scientific publication.		
I understand that personal information collected about me that can identify me will be completely removed from any data source related to this study.	□	□
I agree that my information can be quoted anonymously in research outputs.	□	□
Future use and reuse of the information by others		
I give permission for the transcripts and audio recordings that I provide to be completely anonymized by removing all personally identifiable information and any other links to my identity.	□	□
I give permission for the transcripts and audio recordings that I provide to be archived in the research team's password-protected systems so they can be used for future research and learning.	□	□
I agree that my information may be shared with other researchers for future research studies that may be similar to this study. The information shared will not include any information that can identify me. Researchers will not and cannot contact me for additional permission to use this information.	□	□
Signatures		

______________________ ______________________ ________ Name of participant [printed] Signature Date		
For participants unable to sign their name, mark the box instead of sign I have witnessed the accurate reading of the consent form with the potential participant and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely. ___________________________ ________________________ _________ Name of witness [printed] Signature Date		
I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting. _________________________ ___________________ ________ Researcher name [printed] Signature Date		

Appendix I: Interview Guides

Interview Guide I1: Student

Introduction

Thanks for taking the time to speak with me! My name is Noer, and I'm a master's student interested in understanding how students learn self-sufficiently within the context of the Heat Transfer course. More specifically, how self-reflection can help in this process. The goal of this research is to design an intervention that will support you in your learning. The purpose of this interview, specifically, is to gain insight into your learning experiences and challenges during the Heat Transfer course, with a special focus on the HeatQuiz platform. Before we start, I want to assure you that any information you provide will only be used for research purposes. Your identity will be kept anonymous, and any comments you make will be kept confidential. In addition, this interview will be recorded for further analysis. If you wish for the recording or any associated files to be deleted, please tell us, and we will do so. Do I have your consent to proceed with the recording? Great, thank you. Now let's begin.

Course experience

- How would you describe your experience of the Heat Transfer course?
- Can you share any specific aspects of the course that you find particularly challenging?
- How much time have you roughly spent studying for the course?
- At what point during the course did you start studying actively?
- What learning activities did you engage with during the course?
- What type of learning material was most suitable for you? Why?
- How was your time distributed among these learning activities?
- What grade did you obtain for the course?
- Did you expect this? Why?

Self-regulated learning

- How did you manage your learning process for this course?
- What tools or strategies do you use to organize your study schedule and materials?
- How did you assess your own understanding and identify areas where you need more help?
- What methods do you use to test your knowledge and understanding of the course material?
- Do the conclusions ever lead you to change your learning strategy?

HeatQuiz

- What role did HeatQuiz play in your studies?
- How frequently do you use HeatQuiz as part of your study routine?
- What features of HeatQuiz did you find most useful for your learning?

- Can you give an example of a feature that has been particularly beneficial for your learning?
- If any, can you describe the difficulties you faced in using the HeatQuiz platform?
- What uncertainties (related to managing your learning process, topic contents, and course) have you faced while using the HeatQuiz platform?
- How do you address them?

Feedback

- If you could make 1 improvement to the HeatQuiz platform, what would it be?
- If you could make 1 improvement to the Heat Transfer course, what would it be?
- Would you prefer live lectures or self-paced online learning, if they would cover the same content? Why?

Conclusion

So, those were all my questions! Thank you for sharing your insights. Your contribution will help us develop an intervention to better support student learning in the Heat Transfer course. As a next step, the data from this and other interviews will be analysed and used to inform our design of the intervention. If you have any further questions or thoughts after this interview, feel free to send me an email: n.m.g.paanakker@student.utwente.nl. D*o you have any final questions or comments before we conclude? Alright, thanks again for your time. Have a great day!*

Interview Guide I2: Teacher

Introduction

Thanks for taking the time to speak with me! My name is Noer, and I'm a master's student interested in understanding how students learn self-sufficiently within the context of the Heat Transfer course. More specifically, how self-reflection can help in this process. The goal of this research is to design an intervention that will support them in their learning. The purpose of this interview, specifically, is to gain insight into your teaching practices and your perceptions of students' study habits, as related to the HeatQuiz platform. Before we start, I want to assure you that any information you provide will only be used for research purposes. Your identity will be kept anonymous, and any comments you make will be kept confidential. In addition, this interview will be recorded for further analysis. If you wish for the recording or any associated files to be deleted, please tell us, and we will do so. Do I have your consent to proceed with the recording? Great, thank you. Now let's begin.

Course experience

- Could you describe your teaching experience in general?
- How would you describe your experience of student performance over time in the Heat Transfer course?

    - Can you provide an example of a decline in student performance?
    - What do you think caused this?
- How has the transition to a blended learning model impacted student performance?
    - How have students adapted in terms of engagement and participation?

Self-regulated learning

- How do you observe students planning and managing their learning for this course?
    - What tools or resources do you see students use to support themselves?
- What strategies do you use to help students monitor their learning progress?
    - Have you observed any differences in the strategies used by students who perform well versus those who struggle?
- Do students ever engage in self-reflection play during their learning process?
    - Does it ever lead them to changing your learning strategy?

HeatQuiz

- How do you incorporate HeatQuiz into your teaching?
    - Can you provide an example of a specific lesson or activity where HeatQuiz usage proved to be especially effective?
- What 2 features of HeatQuiz do you find most useful for supporting your teaching goals?
    - Can you give an example of how the useful features positively impacted student learning?
- If any, can you describe any difficulties you notice students face in using the HeatQuiz platform?
    - What kinds of feedback do students communicate about these difficulties?
- What uncertainties (related to planning, monitoring, and managing the learning process, topic contents, and course) do students experience while using the HeatQuiz platform?
    - Can you describe any patterns in the uncertainties students face?
    - How do you address them?

Feedback

- If you could make 1 improvement to the HeatQuiz platform, what would it be?
- If you could make 1 improvement to the Heat Transfer course, what would it be?

Conclusion

So, those were all my questions! Thank you for sharing your insights. Your contribution will help us develop an intervention to better support student learning in the Heat Transfer course. As a next step, the data from this and other interviews will be analysed and used to inform our design of the intervention. If you have any further questions or thoughts after this interview, feel free to send me an email: n.m.g.paanakker@student.utwente.nl. Do you have any final questions or comments before we conclude? Alright, thanks again for your time. Have a great day!

Interview Guide I3: Teaching Assistant

Introduction

Thanks for taking the time to speak with me! My name is Noer, and I'm a master's student interested in understanding how students learn self-sufficiently within the context of the Heat Transfer course. More specifically, how self-reflection can help in this process. The goal of this research is to design an intervention that will support them in their learning. The purpose of this interview, specifically, is to gain insight into your supporting role in facilitating student learning and your perceptions of students' SRL skills, as related to the HeatQuiz platform. Before we start, I want to assure you that any information you provide will only be used for research purposes. Your identity will be kept anonymous, and any comments you make will be kept confidential. In addition, this interview will be recorded for further analysis. If you wish for the recording or any associated files to be deleted, please tell us, and we will do so. Do I have your consent to proceed with the recording? Great, thank you. Now let's begin.

Course experience

- Why do you think there is a low passing rate in the course?
- How would you describe your experience of student performance over time in the Heat Transfer course?
  - Can you provide an example of a decline in student performance?
  - What do you think caused this?
- How has the transition to a blended learning model impacted student performance?
  - How have students adapted in terms of engagement and participation?
- How frequently do you answer questions during tutorials?
  - What kinds of questions do you usually receive?
  - How frequently do you interact outside of the classroom (i.e. email, Canvas)?

Self-regulated learning

- How do you observe students planning and managing their learning for this course?
  - What tools or resources do you see students use to support themselves?

- What strategies do you notice students using to monitor their learning progress and understanding?
    - Have you observed any differences in the strategies used by students who perform well versus those who struggle?
- Do students ever engage in self-reflection play during their learning process?
    - Does it ever lead them to change their learning strategy?

HeatQuiz

- How do you use HeatQuiz in your role as a TA?
    - Can you provide an example of a specific activity where HeatQuiz usage proved to be especially effective?
- What 2 features of HeatQuiz do you find most useful for supporting your teaching goals?
    - Can you give an example of how the useful features positively impacted student learning?
- If any, can you describe any difficulties you notice students face in using the HeatQuiz platform?
    - What kinds of feedback do students communicate about these difficulties?
- What uncertainties (related to planning, monitoring, and managing the learning process, topic contents, and course) do students experience while using the HeatQuiz platform?
    - Can you describe any patterns in the uncertainties students face?
    - How do you address them?

Feedback

- If you could make 1 improvement to the HeatQuiz platform, what would it be?
- If you could make 1 improvement to the Heat Transfer course, what would it be?

Conclusion

So, those were all my questions! Thank you for sharing your insights. Your contribution will help us develop an intervention to better support student learning in the Heat Transfer course. As a next step, the data from this and other interviews will be analysed and used to inform our design of the intervention. If you have any further questions or thoughts after this interview, feel free to send me an email: n.m.g.paanakker@student.utwente.nl. Do you have any final questions or comments before we conclude? Alright, thanks again for your time. Have a great day!

Appendix J: Coding schemes

Table J1: Student Coding Scheme

Coding Scheme for Student Transcripts

Theory	Category	Code	Definition	Coding rule
Self-regulated learning	Forethought	Task prioritization	How students organize their tasks in order of importance.	Use when the student discusses setting priorities or allocating resources based on task importance.
		Goal setting	How students establish specific, measurable, and time-bound goals for learning.	Use when the student explicitly mentions setting objectives for their learning.
	Monitoring	Time management	How effectively time is allocated time to study.	Use when the student mentions scheduling or time management to balance study and other responsibilities.
		Use of study resources	How resources like the reader, HeatQuiz, or external resources are used during the learning process.	Use when the student mentions resources like books, course readers, or supplementary materials as part of their study process.
	Reflection	Self-evaluation	How students assess their performance after completing tasks or exams.	Use when the student reflects on their learning or assesses their understanding of a concept.

		Adjusting strategies	How learning approaches are adjusted based on feedback or difficulties.	Use when the student describes changing their study methods or revisiting tasks after facing difficulties
Metacognitive calibration	Judgment of learning	Perceived understanding	How level of mastery of a specific topic or concept is subjectively assessed.	Use when the student expresses their confidence or doubts about mastery of a topic or concept.
		Difficulty estimation	How the complexity level of a task is evaluated.	Use when the student discusses the difficulty or ease of a topic, task, or course material.
	Learning strategy adjustment	Feedback integration	How feedback from teachers, peers, or tools is incorporated into the learning process.	Use when the student describes seeking or using feedback to improve their performance.
Blended learning	Online	HeatQuiz usage	How HeatQuiz is used to facilitate the learning process.	Use when the student mentions interacting with HeatQuiz to support their studies.
	Blended	Cross-modality reinforcement	How multiple formats are used to improve understanding of concepts.	Use when the student describes different resources, like slides and tutorials, to reinforce learning.

Table J2: Teacher Coding Scheme

Coding Scheme for Teacher Transcripts

Theory	Category	Code	Definition	Coding rule

Self-regulated learning	Forethought	Course goal setting	How teachers articulate course objectives and encourage students to set goals.	Use when the teacher discusses course goals with students or encourages them to set goals.
		Planning support	How teachers provide resources or guidance to aid students in planning their learning.	Use when the teacher mentions providing resources to help students organize their studies.
	Performance	Scaffolding learning	How teachers support the learning process to guide students toward understanding.	Use when the teacher discusses providing support to learning tasks.
		Monitoring engagement	How teachers track student engagement with the course.	Use when the teacher mentions levels of participation in learning activities.
	Reflection	Adaptive teaching	How teachers adjust their strategies based on feedback or observed challenges.	Use when the teacher describes changes to teaching approaches in response to student feedback.
		Student reflection encouragement	How teachers encourage students to evaluate their learning.	Use when the teacher describes efforts to prompt students to reflect on their understanding.
Metacognitive calibration	Judgment of learning	Perception of student understanding	How teachers judge students' comprehension based on observation or interaction.	Use when the teacher evaluates student knowledge.

		Feedback effectiveness	How teacher feedback aids in aligning student understanding with course expectations.	Use when the teacher discusses the impact of feedback on student performance.
Blended learning	Blended	Online-offline integration	How teachers combine online and offline elements of the course to create a blended learning experience.	Use when the teacher discusses integrating online and offline activities.
		Format challenges	How technical or pedagogical issues affect the use of blended learning materials.	Use when the teacher discusses student difficulties with blended learning materials.

Table J3: Teaching Assistant Scheme

Coding Scheme for TAs Transcripts

Theory	Category	Code	Definition	Coding rule
Self-regulated learning	Forethought	Planning encouragement	How TAs encourage students to organize their learning process.	Use when the TA mentions advising students to organize their learning process.
	Performance	Learning support	How TAs guide students in solving problems and understanding concepts.	Use when the TA describes assisting students in problem-solving or understanding concepts.
		Engagement monitoring	How TAs evaluate student participation in tutorials or online activities.	Use when the TA comments on students' attendance, or interaction with the course.

	Reflection	Self-reflection support	How TAs prompt students to reflect on their progress or understanding.	Use when the TA mentions encouraging students to evaluate their understanding.
Metacognitive calibration	Judgment of learning	Gap recognition	How TAs identify areas where students lack understanding.	Use when the TA discusses identifying misunderstandings or knowledge gaps among students.
	Learning strategy adjustment	Feedback integration	How TAs help students connect learning tasks with exam requirements.	Use when the TA describes explaining the relevance of learning tasks to exam preparation.
Blended learning	Blended	Online-offline integration	How TAs help students integrate online and offline learning tasks.	Use when the TA describes blending HeatQuiz with offline learning tasks.

Appendix K: Interview Transcript Codebooks

Table K1: Student Interview Transcripts

Student Interview 1 Codebook

Code	Excerpt
Task prioritization	*"I believe I did mark them with, oh, you have to do this by this stage. You have to do this by this day. You have to do this by this way. So, to get a week by week, what do you have to do?"* *"So, there's a thing that, so there's, you have to have some exercises ready by a certain date to get bonus points. And the dates are a bit skewed within the quartile."* *"That kind of gives the idea of, 'Oh, I have a lot of time for part one.' And then you get really busy for part two and three."*
Goal setting	*"And I believe I did mark them with, "Oh, you have to do this by this stage. You have to do this by this day. You have to do this by this way." So, to get a week by week this told me what to do."* *"Usually, I study from week one quite diligently in general."*
Time management	*"Something like 6 to 8 hours maybe. Maybe a little less, depending on what's the topic."* *"For some topics, it could be, like, three to four hours, like for the conduction and convection parts."* *"On average, maybe overall, maybe 5."*
Use of study resources	*"I usually started by skimming the online lectures for stuff I did not understand."* *"Afterward, I would make the assignments that were in the reader."* *"I basically used the reader assignments, the reader exercises, to figure out whether I was, well, sufficiently prepared for it."* *"At some point, I had to backtrack a little. I definitely did not start at the end."* *"I found that at least the exam was more oriented towards an engineering solution, if that makes sense, in the sense that you don't really need to derive anything."*

Self-evaluation	*"So, like, I basically used the reader assignments, the reader exercises, to figure out whether I was, well, sufficiently prepared for it. And, eventually, there was, I believe, one or maybe two exercise exams. I also used those near the end to find where my weak points were."* *"No, I just went back into the two lectures to see, you know, to get a quick review or look at my notes and try the assignments again."* *"I passed the first one, so I didn't do the second one."*
Adjusting strategies	*"I adjusted something which was already presented to us, which was already given to us. It's yeah, it was, I believe, just a table with all the contents of the course for all subjects."* *"And when I started making mistakes, I did not really understand the topic. I just went back to the lectures."*
Perceived understanding	*"I usually started by skimming the online lectures for stuff I did not understand. And if I found something that I didn't understand or for a refresher, I just repeat it or just listen to it and take some notes. And, afterward, I would make the assignments that were in the reader. And I believe I did also do most parts of HeatQuiz itself."* *"And when I started making mistakes, I did not really understand the topic. I just went back to the lectures."*
Difficulty estimation	*"And I found that, yeah, a lot of things about that question were a whole lot more time-consuming and, well, on a much more advanced level than any radiation question we got during the course from the reader."* *"You get an incentive to do those exercises for which you get bonus points. You might hyper-focus on those exercises. And then you walk into the exam and it's like, "Oh, shit!"."*
Feedback integration	*"Well, if you do the HeatQuiz itself, like the questions there, and if you have a wrong answer, there would immediately be an answer sheet presented to you with the correct way of thinking. That was usually quite extensive, such that you can really understand what you did wrong."* *"Since you get immediate feedback, there's a lot of different situations for which you can test yourself. So, that's good."*
HeatQuiz usage	*"Well, actually always, since I believe I went through the videos through HeatQuiz. At some point, I also just went on YouTube."*

	"I mean they do lead you through the coursework pretty well. So, you basically take the online lecture, you take the quiz or you make the questions regarding it. So, yeah, to an extent I definitely did it." *"Since you get immediate feedback, there's a lot of different situations for which you can test yourself. So, that's good."*
Cross-modality reinforcement	*"Instead, we, of course, did have HeatQuiz and all the online lectures which were prerecorded and available to us. And of course, they are great study material, but again, in my opinion, it should be an addition, and it should not be the core of a course."* *"I mean, if there were at least tutorials, then you could just sit there and study with like-minded peers. And if you would run across a problem and there were problems with the assignments, like annoying small problems which made it basically impossible to solve some assignments. But you could very easily just go to a TA and clear it up immediately.*

Student Interview 2 Codebook

Code	**Excerpt**
Task prioritization	*"You need to effectively disregard the other courses in that module to complete this. So, it's either this or it's the other ones, but you can't do the full module anymore."* *"If I'm stuck on something for a lot longer, maybe it's that specific topic, so I'll skip over to the next question and move on with that and then circle back and try and solve the question that I was stuck on because maybe I had a light bulb on it."*
Goal setting	*"Usually, I try to keep a kind of loose goal, if you will, of 'in this week' or 'in this day' I want to try and have these questions covered."*
Time management	*"Depending on the course or how difficult I find the course, I try and set aside in a week a set amount of hours to work through them."* *"Weekends I only use kind of as an escape because I find trying to balance studying and like private life relatively easy to not or like important to not to burn out. So I try to keep my weekends free."*

Use of study resources	*"I'll sit down with a book. I'll open it up. I'll go read through it and I'll try and see if I can understand what's being said in the book."* *"I use the course reader to kind of like understand the approach of how Wilko or how the professor basically goes with it."* *"For the pure mathematics of it, I go with the reader or the book."* *"Throughout the course itself, I'll go to the books. I'll try to solve the questions that they asked there."*
Self-evaluation	*"I sometimes just run through one of the HeatQuiz things where there is a lot of math involved and I'll just punch in a wrong number or wrong value and just run it through and see the tips that are given afterward."* *"If I'm right with the units, then I understand that. So if I got the math part of it right, then I assume that I understand the theory behind it."*
Adjusting strategies	*"I try and see if I can adjust my style of learning to the course to see what I think would be best."* *"I found that going along with the course doesn't necessarily help me usually, so I'm already deviating quite a bit, and then I just try and add more hours to it or I see that I get some help from somewhere."*
Perceived understanding	*"For me personally, if I were to not pass a course, but I actually understand how it works or like the concept of it, that's more valuable to me."* *"I explain the topic to them and if they get the idea … then I go off with, 'OK. I seem to have learned this aspect within the course.'"*
Difficulty estimation	*"To get the general idea of what you need to cover in the course is relatively easy to get it to the level that Wilko expects of you. That is the difficult part."* *"There's all these tricks or like little, I guess, nuggets that you need to know per content in the course."* *"I just get too distracted trying to focus on the questions, and if I do, sometimes it's just I go to the tutorial to have a specific question that already have answered."*
Feedback integration	-

HeatQuiz usage	*I've tried to avoid the HeatQuiz thing because I'm just get more annoyed with it."* *"I sometimes just run through one of the HeatQuiz things where there is a lot of math involved."* *"For the pure mathematics of it, I avoid the HeatQuiz thing entirely."* *"Having had those Quizlets, if you pass all of them, which you get infinite amount of tries within a half hour. You can just like bash through them quickly."*
Cross-modality reinforcement	*"So, you have the videos, you can have the lecture slides I can refer to. Then you have the little quizzes that you can do in individual steps."*

Student Interview 3 Codebook

Code	**Excerpt**
Task prioritization	*"I made a list of chapters that we had to read, and I made a list of problems that we had to solve, that was given as homework."* *"During the day I was watching those lectures, making notes, and then in the evening I was making problems."* *"But then, still, even writing notes, it's not enough because you have to revisit them. So, I made notes with a lot of colors."*
Goal setting	*"I said to myself, 'Okay, then is the exam. That means I need to, per evening, do so many exercises.'"*
Time management	*"Normally I spent, one, two, three, four, four… four and a half hours an evening."* *"I study in the evening, so after dinner, that's my time, until 11, 11.30, or 12, sometimes I study."* *"During the day I was watching those lectures, making notes, and then in the evening I was making problems."* *"When I saw two weeks before the exam that I would not manage doing the, finishing the exercises and doing the mock exam before the exam, I had some still leave from work at the back of my hand that I could use."*
Use of study resources	*"I was making a pretty condensed notes. I'm very focused on making notes of things that are being said, putting them, you know, in boxes using colors so that it distinguishes itself."*

	"Luckily, they were recorded because still it was a lot of information. So I during the lecture I could write less so I still had to consult the recording to make the notes and do the notes but even though I still found it that my notes from the first part of lectures that were pre-recorded were better than from the second one when they were live because there was really a lot of information on the slides as far as I remember." *"But then, still, even writing notes, it's not enough because you have to revisit them. So, I made notes with a lot of colors. If you want, I can even give you a screenshot or whatever, then you can see how they looked. And it helped me kind of fish out and organize it in my brain."*
Self-evaluation	*"Whenever I did the exercise, I compared it with the notes or with the solutions that I could either they were provided, or I had to find them."*
Adjusting strategies	*"So I was comparing the answers, sometimes I redid the exercise once again to get the understanding, and then tick off, cross out, next."* *"When I saw two weeks before the exam that I would not manage doing the, finishing the exercises and doing the mock exam before the exam, I had some still leave from work at the back of my hand that I could use."*
Perceived understanding	*"So, it was kind of nice, it was very intense, but I think I learned more from that kind of lectures than when you have live and they are very condensed that you are not even able to make notes because it goes so quick."* *"OK, I found it really horrible when I have a book with answers, there's only answer giving, but there was no way, I mean no recipe and no follow up of how you reach that answer because then I cannot check where I made a mistake, and where I have this thinking misalignment, let's say."*
Difficulty estimation	*"They (the exam questions) were more difficult than those tutorials. But maybe it's also the impression that I had, that's my perception because there were also a lot of them."* *"It was becoming gradually more difficult, but I think also what I experienced was that the most difficult parts were at the very end and then you only have this one week overlap before the exam."*

Feedback integration	*"He was kind of asking question he tried to guide me but I'm a person that I learn the best if I have a recipe and I can follow it and I can then I start seeing the pattern."* *"So, it was kind of nice, it was very intense, but I think I learned more from that kind of lectures than when you have live and they are very condensed that you are not even able to make notes because it goes so quick."* *"So, I was learning the most when I had a problem, I could do the problem, I could check the answers immediately. So, if I couldn't get to the answers immediately, that was like, oh, wasting time and not so efficient."*
HeatQuiz usage	*"With thermodynamics was also the HeatQuiz. And I found it useful because it was developed more. You could answer the questions. There were more questions in it. You were when you were giving an answer, and there was a wrong answer, still there was answer given about why? I mean, what was the, not like really that, what was the correct answer, well, yes, what was the correct answer, but also why your answer was not correct."* *"And I also found it nice that there was, when you have gone through a list of questions, and I don't remember how many questions there were, 'cause in one sitting, you could just, you know, that you wanted to start doing the assignment, that was the HeatQuiz, and there were a number of questions. So, you've done those questions, and you could redo the questions, there were different questions. So, that was awesome."* *"So, that's why I used the HeatQuiz to kind of automatize the first multiple choice questions to have more, boom, boom, boom, automatic answer to gain time, to have more time for those open questions."*
Cross-modality reinforcement	*"Luckily, they were recorded because still it was a lot of information. So I during the lecture I could write less so I still had to consult the recording to make the notes and do the notes but even though I still found it that my notes from the first part of lectures that were pre-recorded were better than from the second one when they were live because there was really a lot of information on the slides as far as I remember."*

Student Interview 4 Codebook

Code	**Excerpt**
Task prioritization	*"I think I was following by the week. So whatever lecture they were doing or like it was being like, um, the lecture we were supposed to do for that week or whatever. Then I would just do it the day before."* *"I always try to keep one lecture ahead. So then if I have questions, then I can ask them."* *"I just write some notes, what I think is important from the reader. And then I just go to the class the next day where I can just listen rather than write."*
Goal setting	-
Time management	*"No, slowly built up. Because you can't really be fully like going in the beginning because in the beginning you still have to do some, you still have to understand the theory. So, in the beginning it's more like, "Oh, okay, I'll watch the lectures and then, okay, after I watch the lectures, I'll take some notes."* *"And I did conduction and convection like I was saying quite well, because that was kind of the time I had, and then radiation, I kind of not have enough time for, even though of course it's a big part of the whole, of the course in general."* *"A lot. It was very time-consuming. During this module, we had Fluid Mechanics, Heat Transfer and the Project. And Fluid Mechanics was quite easy, I would say. It did not require a lot of time. The project was time-consuming as well as Heat Transfer. So, the whole module was just working on Heat Transfer and the Project, and Fluid Mechanics was kind of on the side."* *"It was the night of the exam and I was trying to do as much as I could, staying till 12 am, just for the exam, the next day, I did not have enough time."*
Use of study resources	*"I also remember that the reader was the most beneficial thing for me to study from because I was, I think the reader had a lot of questions as well, like to like kind of practice problems at the end."*

	"I just would have one screen with the lecture on and one screen with the reader on and then my notebook." *"If a specific term comes up that I don't understand and it's not covered well in the lecture, then I would just Google it and kind of read something about it very quickly."* *"I just write some notes, what I think is important from the reader."* *"And then I had a sub notes kind of only the important stuff that, or for example, stuff that I know are just a pattern that comes in every single exam that like, I want to know by heart."* *"The reader questions were a lot, a lot more representative of what the exam actually looked like."* *"I would maybe ask a friend. If I still can't figure it out, then I would either email the professor or go to his office straight away."*
Self-evaluation	*"For me, I just go to the lecture, but like I said, I always try to, if there's reported lectures or a reader, I would always like to take my notes, to take some notes, like read through the reader, take some notes on what I think is important."* *"And once I'm, in my opinion, once I'm able to solve all the past papers, or like all like questions, tutorials, past papers, everything like that, without struggling at all, like, I'm just going, I should read the question, oh, I know how to solve this exactly, I just solve it."*
Adjusting strategies	*"And then if a specific term comes up that I don't understand and it's not covered well in the lecture, then I would just Google it and kind of read something about it very quickly. Take some notes there. You kind of like also grasp that. So, it all connects at least."* *"And that's why I said radiation, I barely had time to do it. So, I just had to really study very fast. And just kind of try solving some quick questions."*
Perceived understanding	*"The exercises were honestly fine. They were not too difficult. I think they were representative of the exam."* *"I feel like if I didn't have the reader and the lecture, if I only had the lecture, I would be missing."* *"Before you can practice, you have to first understand, but after that, that's also kind of in general, how I approach any subject: I try to get as much as I can in the beginning of like understanding. I depend on practice and understanding from the practice. So,*

	why this happens, why that happens in different questions is, oh, okay. And then I link it back to the theory. And then I write my own notes on the side, my new notes of why things happen.
Difficulty estimation	*"I think it's quite difficult because it covers, like you said, three different topics, conduction, convection, and radiation. For me, at least I did conduction and convection quite well and radiation, I left it until the end. So, I really had to kind of catch up on that very fast."* *"The exercises were honestly fine. They were not too difficult. I think they were representative of the exam."* *"And that's, I think, what kind of was difficult for me in this subject, specifically, because the material is too much to cover. Yeah, so I wasn't able to do that. Yeah, it was too much material to cover."*
Feedback integration	*"Because if I have a question, then from solving the questions, it's a lot also nicer if I can just get immediate feedback on it rather than having to wait."*
HeatQuiz usage	*"Well, we had to use it because it was like there was like a bonus point for, like, solving some quizzes, I think. And so, I kind of just, of course did it because bonus points, why not?"* *"The other ones were not, like, because I remember I did not look at the HeatQuiz questions again, after I was done with the bonus point. So, after I was done with that, I never looked at it again."*
Cross-modality reinforcement	*"Like, I like to the day before just kind of write down the notes. Even if it's very late at night, I just write down very fast. I just write some notes, what I think is important from the reader. And then I just go to the class the next day where I can just listen rather than write. And then usually if I have questions that I didn't get from the reader, I have all the time in the world because I'm just sitting there listening. And whenever he comes to that specific part, I just raise my hand. I just don't understand this part."*

Student Interview 5 Codebook

Code	**Excerpt**

Task prioritization	*"Almost everything was online. So, it made it easier to just push everything back, you know, through the last week or the last two weeks before the exam."*
Goal setting	*"I am structured. I am really good at planning. But then, at the same time when it comes to it, then I don't stick to my planning a lot."* *"I don't stick to my planning a lot because things come up and then at some point, just at the point, like when it's actually time to do it, then I'm not motivated anymore."*
Time management	*"It's always more stressful when you get closer to the exam. Yeah. So, yeah, like not that much in the beginning and then more towards the end."* *"It did help. I think if there were no bonus points, then I wouldn't be that much on track."*
Use of study resources	*"I liked it that you could watch back everything. Normally, you only come back into the slides, but not the lectures themselves. So that was nice, that if you don't understand them, you can still watch the videos."* *"The questions in HeatQuiz, the quiz, like what I said, they are nice, but a lot of people just to pass for the bonus points, they just learned how to answer them instead of really understanding the differential equation."*
Self-evaluation	*"For the exam specifically, I always look at all the exams and then you know what the type of questions they're going to ask and then you actually have high-level questions that prepare you for the exam."* *"I think I'm just older now. And in my master's. So yeah, like in the bachelor's, it was not difficult to… Now, really, I'm like, 'OK, in two years I'll be working, and I want to be good.'"*
Adjusting strategies	*"I just make more questions and see it, check the answers. And revisit the lectures or the lecture slides."*
Perceived understanding	*"The goal is, of course, to understand, but the way that it starts, it's more memorization, I think."* *"HeatQuiz was not by far not enough, I think, for making the exam."* *"They go over a lot of different things within Heat Transfer. And basically, you understand everything a bit, but you don't really understand anything at all at the same time, even if you've got a good grade on the exam."*

Difficulty estimation	*"I think the question was really easy if you made the question in the project. But yeah. And if you did not do it, then it was very difficult because the question itself is difficult."*
Feedback integration	-
HeatQuiz usage	*"The questions in HeatQuiz, the quiz, like what I said, they are nice, but a lot of people just to pass for the bonus points, they just learned how to answer them instead of really understanding the differential equation."* *"Like, yeah, specifically during studying or during like making the quizzes. I don't think I really used it. I don't use the questions for actually studying for the exam."*
Cross-modality reinforcement	*"I liked it that you could watch back everything. Normally, you only come back into the slides, but not the lectures themselves."* *"For the exam specifically, I always look at all the exams and then you know what the type of questions they're going to ask and then you actually have high-level questions that prepare you for the exam."*

Student Interview 6 Codebook

Code	**Excerpt**
Task prioritization	*"I had six courses in that quartile. So, I did it in the last two weeks before the… It was one of those, 'if I can make it, I'll make it, if I can't make it, then I'll do it next year kind of things.'"*
Goal setting	*"Well, my strategy was to pass it. It was to learn the conduction and radiation parts because those were easy and I still know those very well, even now."*
Time management	*"I had two weeks or so to learn the course, and I thought, well, I'm still going to try."* *"I honestly don't know. I think I did the last two, two and a half weeks a few hours a day. I don't know. So yeah, not as much as I should have."*

Use of study resources	*So, I have no experience with the lectures or the tutorials. I just know HeatQuiz and I've been to the exam and that's it.* *“Yes, I read the reader, but the reader, the whole reader was, I believe, 70 pages or so. But yeah, but the slides were much more detailed. And I think the slides tell you much more and give you also a bit more, yeah, how would you say that, give you, learn you how the proper way of thinking of approaching Heat Transfer.”*
Self-evaluation	*“I haven’t spent… no, I should have definitely spent more time on it because I still did not really understand it by the time I had the exam.”* *“I'm glad I passed. That's all I can say. I did not really have any expectations.”*
Adjusting strategies	*“I just memorized it… But the other parts, I know even now and I… learned those properly, but the convection part I would have to do again sometime.”*
Perceived understanding	*“Well, usually I understand things. It's rarely that I don't understand something, but I think I understood most of it. I think just it was very difficult. But I guess that's just a matter of experience or just, yeah, I should have worked more. I should have put more hours in. That's definitely true.”*
Difficulty estimation	*“But I think that is the most difficult part was the convection part. The others were okay. But yeah, I think perhaps they could have given that more attention.”*
Feedback integration	*“I thought that the timing was off… I completely fail quiz one… I go back to lecture two, then I do quiz one again, and then I have everything correct.”*
HeatQuiz usage	*“I think with the way HeatQuiz presented it, you see just obstacles, and it's not a fun way to learn.”* *“I think they could have postponed [the quizzes] a little bit because I felt that the timing was off.”*
Cross-modality reinforcement	*“If it was possible, I would have preferred live lectures. But again, I also do like videos that you can re-watch. I think that this is something new since the pandemic.”* *“If I had only the reader, I think I would have done better.”*

Table K2: Teacher Interview Transcripts

Teacher Interview 1 Codebook

Code	Excerpt
Course goal setting	*“We communicate that during the first lecture. We tell them what to do, what is the purpose of the tutorials.”* *“No, I don’t really mention this, but I think this is something like study skills which is not something that I should teach them in the tutorial.”* *“And yeah, but I know there are also students who plan this and who say, ”OK, I have this tutorial, and these questions are scheduled so I will make these” and they don't write. And some of them, what I also see, is that if they make a question, I have the feeling that they do it for me. And not for themselves.”*
Planning support	*“We don't use it [HeatQuiz] very explicitly. We mention it. There is nothing that says, ”OK you should do it every week”. We say that the module, which is related to that week’s lecture, can help but we also give an explanation during the lecture.”* *“Yeah, actually what would be nice if students do the Heat, the ThermalQuiz, because we divided it in... Yeah, OK. Lecture one, lecture two, lecture three. So that after lecture one, they should be able to do all the questions of lecture one and in the ideal world they should do that.”*
Scaffolding learning	*“And in the tutorial, I think we see less students, maybe yeah, we have 300 students in the course, so maybe 50 students are there and some of them are really studying, they're asking questions and they try to solve things.”* *“So, this was also a way for us to give the students a platform to practice them. Yeah, because you cannot ask multiple-choice questions in the exam if students cannot practice it.”*

	"And they always say, "yeah, I want to see how you can work it out" and if they try it at home, they kind of manage it. If they listen to our explanation, then they should be able to do the others themselves. But then they don't try it at home, so they don't learn from it."
Monitoring engagement	*"No, you see that some students when we explain this go there and play a little bit, but what we see in the end is that students only use it a few days before the exam. Okay, some of them use it a bit more regularly but most of them go there before the exam and not all of them. So, there are some students who never access it, I think."* *"Yeah, it's difficult to make this comment for all students, but in the tutorials... OK, maybe half of the students comes to the lecture, and they sit there."* *"And they don't say that they listen, but some of them are on track, and they can follow it and some others are just there because they think they learn something, they just go there because they think they are expected to go."* *"But the ones who do want to be helped are the ones who then show up and who are actively engaged. They will pass the exam and get the bonus points."*
Adaptive teaching	*"No, and maybe that's something that I can try to change. If I have a way to do that, that they are more familiar with it [materials from the reader or HeatQuiz] or that they are more exposed to it. That's maybe important."*
Student reflection encouragement	-
Perception of student understanding	*"So yeah, I don't talk to them a lot. Yeah, I know that some students are not, what I said, efficient. They are lagging behind and they don't stay up to date. And yeah, when you say this, they say "yeah, I have so many to do, and the exam is so far away."* *"Yeah, and I think a lot of students are just not studying regularly and have to study or start just before the exam and are lagging behind."*
Feedback effectiveness	*"They never talk about this. But maybe that's also because, yeah, they don't use it. I don't know. I never had any complaints or things that they don't know how to use it."*

Online-offline integration	*"At the end of every lecture, yeah, we pose a tutorial question of which the answer is not published."* *"And what I do is, actually, that students work on that question at home. And in the tutorial, I will work it out on the blackboard. Because students always say 'oh we want to see worked-out questions, that helps us,' blah blah blah."* *"For me, I have mostly multiple-choice questions there, and in the tutorial, I'm more focused on open questions... Because the multiple-choice questions are also more focused on understanding and explanation of the theory, while the tutorial questions are a little bit more focused on doing a calculation."* *"I have used it now for three years, two or three years. Maybe two, I'm not sure. Yeah, what I experience is that, at least in my case, it's a little bit of a side thing. So, it's not fully integrated. I think Wilko has it way more integrated."*
Format challenges	*"Yeah, but if you make the tutorials mandatory, you are only busy with administrating who is there, who is not there, and I don't want to force students to go to tutorials because it's a university. It's not a middle school or a high school because, yeah, they have their own responsibility."*

Teacher Interview 2 Codebook

Code	**Excerpt**
Course goal setting	*"It was the second or third exposure to HeatQuiz. When I did my opening lecture, I said, "OK, well, you're all familiar with HeatQuiz?", "OK, so this is the plan. Yeah, this is what we do. But I did not feel any sense of, "Oh, I need to explain what the idea is." No, rightly or wrongly, I thought they were all on board. "* *"But sometimes people jump around a bit more and through the syllabus. And I don't want to be too prescriptive in that."*
Planning support	*"So, what I think has been very clever is the split between a formal tutorial where we expect you to soon work towards exam-level. And much, much further down in the learning is the, "Have you understood the concepts? Have you understood the simplest sums?""*

Scaffolding learning	*“With HeatQuiz, you can actually break it down in really bite-sized pieces.”* *“And I think that's because students... I try to give students always a feeling like, ”Yep, this is never a lost course. You can still catch up.” Even in the last lecture, I will go slow enough for you to hang onto your fingertips.”* *"And to build confidence for the students, it's nice that they can actually do little practice questions.”* *"Yeah, I think the fact is our very short, simple questions takes the fear factor away for some of the students."*
Monitoring engagement	*“And students who perform poorly often make that mistake, ”Oh, it's all there anyway. So yeah, I don't need to.” Yeah. ”I don't need to follow the lecture now. I can still watch the videos in the last week.” And ”I'll play the videos while I'm actually asleep. And then I'll, by osmosis, I'll...“. No.”* *“Because OK, this sounds arrogant, but over the years, students have found it makes sense to follow my lectures.”*
Adaptive teaching	*“So, I used my time instead to fill in some of the gaps in the understanding by picking up the question triggered by other questions. ”Oh, yeah, Johnny asked a question. I've answered John's question, but now Mary asked a follow-up question. This goes back to Johnny's first point.””*
Student reflection encouragement	-
Perception of student understanding	*"Yeah. We marked the first course a few weeks ago, and there was still 20% fail, which actually is not bad for mechanical engineering.”* *“I would say that when I mark, because I typically tend to mark my own exams, that the number of spectacular fails is very low.”*
Feedback effectiveness	*“Yeah, they do let me know. It's typically my answers, but they think the answers are wrong. And sometimes they're right. Sometimes that is correct. The answers are indeed wrong and we have to fix them.”* *“But it was reassuring that the students were willing to speak up. I'd like to think I've got a good rapport with them. They're not afraid to email me. I say, "Yeah, just contact me” and I'll give them a good... yeah, I'll typically respond to anything.”*

Online-offline integration	*"I would say for 80% of the students it's practice. It's a bit of benchmarking your rhythm, your discipline. "OK, well, this is the number of hours you need to put in." Maybe for the 20% who struggle it could be filling the gaps as in, "Oh, OK, I've really not understood the lecture. Let's go through HeatQuiz first. And then, yeah, then I can ask intelligent questions."* *"So, during the tutorials that we had, there were questions about the tutorial sheets that you would expect. But also, questions about the HeatQuiz questions where students were talking to each other and me at the same time about particular HeatQuiz concepts."* *"Anyway, so on Heat Quiz, what is nice about it, the duality, is I explain stuff in the lecture. It's quite theoretical. And to build confidence for the students, it's nice that they can actually do little practice questions."*
Format challenges	*"The platform is fine. I've not heard anything, complaints about the platform. It's just that the platform has been populated with content, and sometimes the content has just not been sanity-checked sufficiently."*

Teacher Interview 3 Codebook

Code	**Excerpt**
Course goal setting	-
Planning support	*"Yeah, we are using actually really intensively HeatQuiz in a manner that we are providing the students this learning path and telling them, "OK, this week you should have done this stuff," for example."*
Scaffolding learning	*"We explain the question to them. We are making a really comfortable exam situation for them in order to let them get rid of this stress condition in the exam.""* *"We are there, but we are not giving them, for example, the end answer to the question. We are guiding them in a way that they can proceed step by step to approach the answer at the end. This is the concept that we have in our self-calculating task."*

	"But the HeatQuiz itself, if you mean only the quizzes that they are solving, these are an extra learning material, which is not included in the main learning path. The main learning path is based on the lecture slides and the videos that they are watching, and these quizzes are simply helping them to understand better these materials." *"And we have several things that we are making available for the students. These are, for example, lecture videos, exercise sessions and in two different ways we have exercise sessions, where we solve the questions for them. We have another exercise session where we give them the question and we ask them to solve it and if they have any problem, they can actually ask our colleagues. And we have our lecture videos. It means that they have to look at the videos before the class, come to the class and ask their questions and discuss with the lecturers. And at the end, we have also these HeatQuiz stuff where we are asking or where we are making quizzes to the students available such that they can actually go to these quizzes after each lecture video in order to make their knowledge or in order test themselves in order to see how they are understanding this stuff or how good they can actually apply their knowledge to solve the questions. And in addition, we have also provided them with these consultation hours at our institute. It means all in all, it requires a really organized participation in the lecture stuff."*
Monitoring engagement	*"We have actually HeatQuiz in itself, which has statistical analysis, and you can see there whether the students are using it or not, anonymously, of course. But it depends at different phases of the semester. You can see that the participation is high, and in some phases the participation is low."*
Adaptive teaching	*"Some of them, especially the videos, for example, the lecture videos concerning certain topics that are available also in YouTube, the lecture videos on the learning paths. I have this feeling that some of the lecture videos are too long, and they are transferring too much knowledge to the students within maybe 20 minutes or within maybe 40 minutes. And this should, in any case, be improved in the near future."*
Student reflection encouragement	*"We are making quizzes to the students available such that they can actually go to these quizzes after each lecture video in order to make their knowledge or in order to test themselves."*

Perception of student understanding	*"The most important thing is that I realize, most of the time, some missing fundamentals that they had to actually earn during their studies."* *"This missing knowledge makes them a bit nervous, I would say, also in the exam and in the self-calculating tasks that we are giving to them in our exercise session. I have this experience that they can't recognize or they can't realize where they should do this energy balance or not, or how they should do this. This is one of the main important learning behaviours of them that I realized during the last semester."* *"I'm a bit concerned about it because I had this feeling over the last semester that the students sometimes are overloaded with their stuff. We have to find a way that they could have the feeling that they are not overloaded, but all this stuff is somehow to help them in order to bring them at a point where they can actually judge and master the course from their perspective."*
Feedback effectiveness	*"In most cases, I am discussing with them why I am doing my energy balance in that way, where are the balance borders or where is my control volume, for example, to do the energy balance and why I choose that in that way."* *"We are there, but we are not giving them, for example, the end answer to the question. We are guiding them in a way that they can proceed step by step to approach the answer at the end. This is the concept that we have in our self-calculating task."*
Online-offline integration	"And we have several things that we are making available for the students. These are, for example, lecture videos, exercise sessions and in two different ways we have exercise sessions, where we solve the questions for them. We have another exercise session where we give them the question and we ask them to solve it and if they have any problem, they can actually ask our colleagues. And we have our lecture videos. It means that they have to look at the videos before the class, come to the class and ask their questions and discuss with the lecturers. And at the end, we have also these HeatQuiz stuff where we are asking or where we are making quizzes to the students available such that they can actually go to these quizzes after each lecture video in order to make their knowledge or in order test themselves in order to see how they are

	understanding this stuff or how good they can actually apply their knowledge to solve the questions. And in addition, we have also provided them with these consultation hours at our institute. It means all in all, it requires a really organized participation in the lecture stuff." "Yeah, we are using actually really intensively HeatQuiz in a manner that we are providing the students this learning path and telling them, 'OK, this week you should have done this stuff,' for example. But the HeatQuiz itself, if you mean only the quizzes that they are solving, these are an extra learning material, which is not included in the main learning path. The main learning path is based on the lecture slides and the videos that they are watching, and these quizzes are simply helping them to understand better these materials."
Format challenges	*"I had this feeling during the last semester that maybe making too much stuff available for the students might overload the students."* *"Some of the lecture videos are too long, and they are transferring too much knowledge to the students within maybe 20 minutes or within maybe 40 minutes."* *"And they should know that mastering HeatQuiz app in itself, just, I mean, only solving the quiz questions, is not enough to pass the exam."* *"The negative aspect of the whole idea of a HeatQuiz and learning paths is that the students could stay at home and start learning stuff like a virtual university, which has to be prevented somehow."*

Table K3: Teaching Assistant Interview Transcripts

Teaching Assistant Interview 1 Codebook

Code	**Excerpt**

Planning encouragement	*"But on the other side, I mean, they're bachelor students, they should be able to handle some kind of freedom themselves and make their own planning."*
Learning support	*"The most interaction with the students that I had was just explaining to them how to solve a specific task."* *"And then the other part of the students that, well, of the 10% that already attends, the 5% of those students who ask the questions, they really have the in-depth questions, and they want to have someone with whom they can discuss on a high level about the course material. I think that's your expectation of those students."*
Engagement monitoring	*"I would repeat myself probably, but I think the larger difference is that the students who pass also kept up with the planning of the course."* *"We often had a specific set of students who really came to the tutorials to ask questions to the teaching staff. But I think about maybe 80, 90% of those students who attended the tutorials just went there to sit and do the exercises."* *"I feel like maybe the students who do attend the tutorials are also the more serious students, so to say. And I think those who don't attend might be the students who like to have freedom, but then they also maybe prioritize things above the course, so to say."*
Self-reflection support	*"Even though you might understand those quizzes, they are only the first step towards getting you to the exam level. And it's something that we repeatedly said to them."*
Gap recognition	*"I often got questions about tasks that were from one or two weeks ago already. So in the first few weeks, you already saw that they were lagging behind."* *"So from the question that I got during the tutorials, it was already only 10% of the total students, but I think more than half of them were lagging behind. So, a really large portion of the total students."*
Feedback integration	*"I think it would be really good that the bonus points that the students currently get, that they would also be awarded if they did the tutorial exercises so we can push them to doing that as well."*

	“And within the course reader, we have a few paragraphs on demonstration. So, it's simply me picking up such a task, showing how I should do it. And then I also apply the systematic problem approach. But also, even within the solutions of the exams.” *“So, they always have those exams at Newton, I think the study association, but also on campus. We also provide the solutions with that approach that we apply for the course.”*
Online-offline integration	*“But as I said, these exercises are also available on HeatQuiz. So, it's not that you should go to the tutorials. You can also do the tutorial exercises at home with pen and paper. I mean, where you do them is up to you. Yeah. It's not that there is a gap between those who attend the tutorials and those who stay at home, they all have the same materials."*

Teaching Assistant Interview 2 Codebook

Code	**Excerpt**
Planning encouragement	*“But yeah, I'm sure in the end, right, students know for themselves how they should study.”*
Learning support	*“I would be explaining it in a way that I think was a very good starting point for them to use, to get a feeling of how to approach the problems. I think that the larger assignments are very important as well as you probably heard by now. I also advised them not to hang on to these assignments too much. Also, when you feel a little bit confident, try the larger assignments. So, I was splitting it up a little bit.”* *“The students that do ask questions, they really do want to fundamentally understand, like, ‘OK, why are we doing this, this and this step, right?’ They kind of know when they see it, right? They see the solution and they understand, like, ‘OK, these are the steps,’ but why are we taking the steps, right? They want to understand why should we use this approach, but why shouldn’t we use this other approach, which we also learn?” (Helping students understand problem-solving approaches.)*

	"Sometimes I just have to walk to the students where I saw like 'OK, now you filled in the same question five times let me help you,' but they didn't really reach out themselves." *"Well, in the end, like, yeah, I do think there's like the, of course, if the lectures, you have a lot of, like, at least when I was still a student, there were a lot of like contact hours. So, you had the lectures, you had the guided tutorials, and then you had the self-working tutorials as well. And there's plenty of material. So, you have, of course, the HeatQuiz and you have a lot of, like, the more general assignments you can make. And there's even, like, the book of formularies, which I think is quite nice. Like sometimes, like, often you don't really have a book for a course, but having the book of formularies, which really condenses all the equations and things you have to use into a single booklet is very nice. So, I do think that there's like plenty of material and support for the students to achieve it."*
Engagement monitoring	*"But I think that you only hear from like 10%. And it's not that weird. I've been TA for other courses. And for a lot of courses, you have a lot of students who just study by themselves."* *"It's [HeatQuiz] so well laid out that it might make the students a bit lazy that they're just like everything is already there so why should they put in the effort to find new material themselves."*
Self-reflection support	*"Sometimes I just have to walk to the students where I saw like "OK, now you filled in the same question five times let me help you", but they didn't really reach out themselves. They were just really staring at HeatQuiz and just going through it over and over and over again without really like stepping out of the HeatQuiz environment, I feel."*
Gap recognition	*"Sometimes the explanation didn't really work and then they didn't sometimes ask questions where I thought like, 'OK, if you now just ask me OK I've been looking at this same answer for five times and every time I'm still answering it the wrong way could you explain it to me,' they weren't really asking it themselves."*
Feedback integration	*"If, for example, in the guided tutorials, I think there would always be just one example. And it's a bit tricky because then they, of course, made an example which is really easy to solve. But when you get into a real-world example or, right, the exam, the real-world example isn't guided."*

Online-offline integration	*"It's the students who, like, have limited time they want or have to invest in the course. They feel like they'll just start with the HeatQuiz. And if you have time over or like the more motivated students, they then only after that go to the assignments. But I think that the HeatQuiz can be a good introduction, but you really should keep it to an introduction and move to these more elaborate assignments, because these are way more reaective of like the entire set of skills you move out."*

Appendix L: Preliminary Evaluation Instruments

Appendix L1: Structured Observation Protocol

Purpose

To help teachers and TAs systematically observe how students engage with the process worksheets during in-person sessions. The focus of the observation should be on usage patterns, and engagement levels. This may reveal areas for improvement that can be incorporated into the next version of the worksheets.

Instructions

During the session, teachers/TAs should observe and record the following:

- **Engagement**
    - Are students actively filling in the worksheets? *(Yes/No)*
    - Do they reference the worksheets while solving problems? *(Frequently, Occasionally, Rarely, Never)*
    - Do students collaborate with peers using the worksheets? *(Yes/No)*
- **Challenges**
    - Do students appear confused about any part of the worksheet? *(Frequently, Occasionally, Rarely, Never)*
    - Are there frequent pauses or requests for clarification? *(Yes/No)*
- **Alternative Behaviours**:
    - Are students relying on other materials (e.g., HeatQuiz, notes, reader) instead of the worksheets?
    - Are they skipping steps or solving problems without using the worksheet?

Appendix L2: Interview Guide (Evaluation)

Introduction

Thank you for participating in this interview. We are gathering feedback on the process worksheets used in the Heat Transfer course to understand how they support your learning or how they may be improved. Your insights will help refine the intervention and greatly benefit future Heat Transfer students!

Questions

- Can you describe how you used the process worksheets during the course, both in and outside of class?
- How clear and easy-to-follow did you find the instructions and layout of the worksheets?
    - *Follow-up:* Were there any specific steps or sections you found confusing or difficult to use?
- How did the worksheets influence your approach to solving the exercises from the reader or old exam questions?
    - *Follow-up*: Did they help you feel more prepared for similar problems on the exam?
- Did the guiding questions in the worksheets help you during problem-solving?
    - *Follow-up*: What would make them more effective?
- What changes would you suggest to improve the worksheets?

Closing

Thank you for sharing your experiences and suggestions. Your feedback will directly inform how we improve the worksheets for future students. Have a nice day!