Taylor & Francis
Taylor & Francis Group

European Journal of Engineering Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ceee20

Introducing 'Concept Question' writing assignments into upper-level engineering courses

Kirsten A. Davis, William A. Mogg, David P. Callaghan, Greg R. Birkett, David B. Knight & Katherine R. O'Brien

To cite this article: Kirsten A. Davis, William A. Mogg, David P. Callaghan, Greg R. Birkett, David B. Knight & Katherine R. O'Brien (2021) Introducing 'Concept Question' writing assignments into upper-level engineering courses, European Journal of Engineering Education, 46:6, 931-950, DOI: 10.1080/03043797.2021.1943649

To link to this article: https://doi.org/10.1080/03043797.2021.1943649

Published online: 16 Jul 2021.

EUROPEAN JOURNAL OF ENGINEERING EDUCATION
2021, VOL. 46, NO. 6, 931–950
https://doi.org/10.1080/03043797.2021.1943649

Introducing ‘Concept Question’ writing assignments into upper-level engineering courses

Kirsten A. Davis [a], William A. Mogg [b], David P. Callaghan [c], Greg R. Birkett [b], David B. Knight [d] and Katherine R. O’Brien [b]

[a]School of Engineering Education, Purdue University, West Lafayette, IN USA; [b]School of Chemical Engineering, University of Queensland, Brisbane, Australia; [c]School of Civil Engineering, University of Queensland, Brisbane, Australia; [d]Department of Engineering Education, Virginia Tech, Blacksburg, VA, USA

ABSTRACT

In this paper, we introduce ‘Concept Questions,’ a weekly writing assignment that has been incorporated into multiple upper-level engineering courses at a single university with the intent of enhancing students’ conceptual understanding of the course content. To explore the influence of this activity on students in these courses, we compared students’ scores on the Concept Question assignments with their final exam scores, analysed students’ open-ended responses to questions regarding their learning in the course, and surveyed students who had taken these courses in previous semesters to understand how the Concept Question assignments may have influenced their learning approaches in subsequent courses. Our analysis revealed that students highlighted a variety of learning outcomes from the Concept Questions assignments and their performance on the assignments was correlated with their final exam scores. However, most students did not report that these assignments had changed their learning approaches overall. This paper supports prior work suggesting that such assignments can be helpful in individual engineering courses, but further work is needed to explore student learning across courses.

ARTICLE HISTORY
Received 28 August 2020
Accepted 7 June 2021

KEYWORDS
conceptual understanding; writing assignments; learning approaches; student perspectives

To prepare engineering students for success in engineering work environments, it is important that they develop the ability to transfer knowledge from the classroom to the workplace (Bransford, Brown, and Cocking 2000). However, gaps have been identified between the types of problems that students typically solve in the engineering classroom (i.e., often closed-ended in structure) and the more open-ended problems addressed by engineers in the workplace (Jonassen 2014). Developing conceptual understanding of engineering content is one way to help students transfer their knowledge between settings because the concepts transfer, whereas the procedures of solving the problem may not (Streveler et al. 2008). Research of engineering work has suggested that growth in conceptual understanding plays a significant role in how engineers approach open-ended problems in the workplace (Bornasal et al. 2018). However, traditional engineering problem sets do not provide students the opportunity to learn how to approach problems in this manner. This study explores one type of assignment that provides students with the opportunity to approach course content through a more conceptual lens.

The purpose of this study is to explore students’ perceived learning following a writing assignment focused on Concept Questions in upper-level engineering courses. We consider students’

CONTACT Kirsten A. Davis kad@purdue.edu
This article has been republished with minor changes. These changes do not impact the academic content of the article.

perceptions of learning within the specific courses with the intervention as well as in students' subsequent engineering coursework and address the following research questions:

RQ1: What do students describe having learned in the courses that embed writing assignments focused on Concept Questions?

RQ2: What relationships exist between students' Concept Question work and their final exam grades in the courses?

RQ3: What learning approaches do students who have completed courses that embedded Concept Questions use when learning further engineering course content?

Our study contributes a unique longitudinal evaluation of a research-based pedagogical intervention in that we collected student perspectives both at the end of the courses as well as several semesters later. Through our findings, we provide an enhanced understanding of student approaches to learning in upper-level engineering courses that seeks to overcome some of the shortcomings of focusing on procedural, as opposed to conceptual, knowledge building.

Literature review

Over time, different learning theories have emerged that correspond with different approaches to teaching and learning. The oldest approach is the behaviourist view of learning, which suggests that knowledge is a collection of facts (or responses) which can be learned in response to specific questions (or stimuli; Greeno, Collins, and Resnick 1996). Assignments that focus on students performing observable behaviours or procedures align with this learning theory (Newstetter and Svinicki 2014). An alternative approach is the cognitive view of learning, which suggests that knowledge focuses on concepts and cognitive abilities which are best learned through inquiry-based activities that allow the learner to construct an understanding of the course content (Greeno, Collins, and Resnick 1996). The situated learning framework has emerged most recently and suggests that knowledge is distributed across people and their environment (Greeno, Collins, and Resnick 1996). Learning in this framework involves moving from peripheral to full participation in a community of practice, and thus assignments might focus on self-reflections or portfolios demonstrating such participation (Newstetter and Svinicki 2014). Our focus on conceptual understanding in this study is grounded in constructivist learning theory, which falls most squarely within the cognitive approach to learning. However, the design of the concept question assignments is also informed by the situated framework's focus on presenting engineering problems in authentic environments (Johri, Olds, and O'Connor 2014).

Conceptual understanding refers to an individual's beliefs about how concepts relate to each other, forming mental models. Mental models are the collections of concepts and beliefs that the individual uses to explain phenomena (Streveler et al. 2014). Engineering graduates have been found to lack understanding of foundational engineering concepts, making conceptual change a focus in engineering education research (Streveler et al. 2014). Conceptual knowledge is differentiated from factual knowledge (i.e., knowledge of terminology), procedural knowledge (i.e., knowledge of techniques and methods), and metacognitive knowledge (Krathwohl 2002). In engineering education, it can be easy for students to focus on procedural knowledge (i.e., how to solve a problem) without developing the associated conceptual knowledge (Venters, McNair, and Paretti 2014). Such an approach hinders students from developing expertise in the field, which requires both procedural and conceptual knowledge (Bransford, Brown, and Cocking 2000; Venters, McNair, and Paretti 2014). To help students develop conceptual understanding, it is important to support students' ability to develop mental models and general problem-solving approaches within a domain (Greeno, Collins, and Resnick 1996). Our study presents an example of how such support can be provided within upper-level engineering courses, where it is important for students to move beyond abstract and compartmentalised understanding of engineering concepts toward learning to apply these concepts in more complex and contextualised situations (Bornasal et al. 2018; Lord and Chen 2014).

A related branch of research has explored students' approaches to learning. Beginning with studies in Sweden, researchers described surface and deep approaches to learning (Biggs 2003; Marton and Säljö 1976a). A *surface approach* is characterised by low-cognitive effort activities when more complex understanding is actually required; an example of this approach is memorising facts rather than interpreting or synthesising information. On the other hand, a *deep approach* to learning occurs when students seek to understand the content being presented, exploring both details and the big picture (Biggs 2003). The learning approaches students use can be connected to their academic performance (Biggs 1985) and is influenced both by student characteristics and their learning environment (Biggs 2003). In particular, students' interpretations of their instructors' expectations communicated via assessments can inform students' decisions about how to approach learning new content (Biggs 1993; Marton and Säljö 1976b). Thus, incorporating assignments that encourage a deep approach to learning is an important step that instructors can take in supporting students' development of conceptual understanding.

Within engineering education, this idea of learning approaches has been explored specifically in the context of solving engineering problems. Venters (2014) interviewed students in statics courses about how they solved problems and asked them to talk through a problem using a think-aloud protocol. Based on these interviews, Venters (2014) characterised student learning approaches as a spectrum ranging from conceptual to procedural. Students fell at different places on this spectrum, although most were either heavily procedural or balanced between the two ends. Students with a *procedural approach* to learning focused on more algorithmic or step-by-step methods for solving problems. A *conceptual approach* to learning involved making efforts to understand the concepts behind engineering problems, perhaps through referencing notes or the textbook. Students using a *balanced approach* focused on developing both procedural and conceptual knowledge at the same time, often describing these types of knowledge as inseparable (Venters 2014; Venters, McNair, and Paretti 2013, 2014). Based on the earlier studies related to learning approaches, the design of course assignments may be one way that instructors can support students in developing a more balanced approach to learning engineering concepts (Biggs 2003; Marton and Säljö 1976b).

Prior studies have explored how pedagogical interventions can help students develop conceptual understanding in different engineering courses (e.g., Goncher et al. 2015; Hermundstad et al. 2016; Meyer et al., 2015a; Venters, McNair, and Paretti 2012). Many misconceptions stem from having inaccurate mental models or assumptions about a topic, so an important part of the learning process is helping students communicate their mental models and assumptions (Streveler et al. 2014). An increasingly common approach is incorporating writing, reflection, or metacognitive activities into engineering classrooms. For example, Venters, McNair, and Paretti (2014) used written 'process problems' in statics classes, where students had to describe their process for solving a problem in words. This study found that students in course sections that assigned these problems were reflecting on why they were approaching problems in certain ways, an important step in connecting procedural and conceptual knowledge. Goncher et al. (2015) compared this approach with having students respond to concept-focused questions, finding that the different types of questions revealed different aspects of students' understanding. In addition to having students respond to a conceptual question, Meyer et al. (2015a) asked students to rate several responses of varying quality to the same question. Students in this study suggested that seeing different ways of responding helped them understand the level of understanding expected in such problems and recognise gaps in their own understanding. These types of assignments build on earlier examples of incorporating writing into engineering courses to develop communication skills (Hanson and Williams 2008). Thus, building such assignments into engineering courses has the potential to benefit students in various ways.

In our current study, we sought to understand these various potential benefits of our 'concept question' assignment. Although the studies cited here have also introduced writing-focused and/or concept-focused assignments, our study introduces innovations on this foundation by grounding the Concept Question assignments in real-world environments and contexts (as suggested by the situated learning framework) and by providing students opportunities to resubmit the questions after receiving a first round of feedback (as suggested by the constructivist learning framework). Further, our research explores not only grade-based outcomes of this intervention, but also students' perceptions of their learning and whether they experienced a change in their learning approach in multiple semesters beyond the course in which they encountered the Concept Question assignments.

Concept Question assignment implementation

This study was conducted at a large research-focused university in Australia. Based on a desire to improve students' critical thinking and communication in a way which encouraged conceptual understanding of material in engineering courses, one of the authors developed an intervention known as Concept Question assignments. We use the term 'concept question' to indicate a short assignment which requires students to demonstrate conceptual understanding, typically in a written answer. This approach differs from more typical engineering problems in that the questions are open-ended rather than asking students to make calculations to provide the 'right answer.' By using the concept question format, the instructors hoped students would shift their perspective of the course content beyond facts and figures to abstraction, allowing them to apply this knowledge to unseen situations and ideally extend it through mathematics or experiments. The purpose of these assignments, as communicated with the students, were to:

- Encourage you to review what you have learned each week and apply that information to solve problems;
- Challenge you to think critically about the fundamentals of heat and mass transfer [or other course content, as specified], and how to communicate these concepts;
- Give you practice in writing concise, precise explanations of important engineering concepts: to work out what the main point is, and how to efficiently communicate that point to others using logic and clarity;
- Provide feedback to the teaching staff about what you are learning.

These assignments were implemented across three different engineering courses in two departments at the same university (see Table 2 in the Methods section).

The Concept Question assignments were short-answer open-ended questions, for which students were required to submit a response of up to one page in length. The assignments were submitted online, but could be hand-written and scanned. The assignment questions were always related to a key concept(s) in the course but the context could vary widely from personal experiences to global sustainability impacts. Responses were graded using criteria based on critical thinking intellectual standards (Paul and Elder 2006). These criteria (shown in Table 1) were developed to strike a balance between clarity to students and fast marking for staff. One of the key elements of the Concept Question assignments was that students were given two submission dates one week apart. If they submitted by the first due date, they received a mark and written feedback within 3–4 days, which they could use to revise and resubmit by the second due date. No written feedback, in the form of comments, was given on assignments submitted on the second date, regardless of whether it was the student's first or second attempt. The maximum mark of the two submissions was recorded as the final mark. The courses were each run over a 13-week semester, with 5–6 concept questions included in each course. Students who utilised the option for a second attempt at each assignment after receiving feedback would therefore submit a response approximately weekly over the course of the semester. See Appendix A for sample Concept Question responses that were provided to students with the marking criteria and Appendix B for the Concept Questions that were used for one of the courses in the study.

Table 1. Marking criteria for concept question assignments.

0	**No correct content**	No submission, or no correct information
1	**Very little correct content**	Very limited correct information
2	**Little correct content**	Limited correct information
3	**Rudimentary observational**	Response contains simple observations with some correct information, with substantial errors or omissions. Wording may be quite unclear and imprecise.
4	**Observational**	Response contains simple observations with correct information. No connections are made between different components of the problem OR some connections correctly made but response contains significant errors. Wording may be ambiguous.
5	**Rudimentary analysis**	Some important connections between different aspects of the problem are identified or explained. May include minor errors or imprecise wording.
6	**Analysis**	Important connections between different aspects of the problem are clearly identified and explained. There may be minor errors or wording may lack precision.
7	**Rudimentary synthesis**	Response identifies and explains the significance of important connections between different aspects of the problem, with some degree of original insight. Writing is quite precise and concise but may include minor errors.
8	**Synthesis**	Question answered with no errors, drawing connections between different aspects of the problem. The answer provides information concisely and precisely, and the significance of the answer beyond this specific problem is clear.

Students in all courses used in this study were provided with the marking criteria (Table 1). Training in critical thinking and communication differed between the courses, and in some cases between cohorts within a course. In Introduction to Environmental Engineering, students spent 1–2 hours developing their critical thinking skills, in a one-hour guest lecture on critical thinking from a philosophy lecturer in 2016, and in completing a two-hour tutorial on argumentation in 2017. In Heat and Mass Transfer, students received example answers to a sample question, with marks and comments attached (see Appendix A), to provide tangible evidence on the difference between observation, analysis and synthesis as defined in the marking criteria (Table 1). In both courses, examples of submissions receiving full marks were posted after each assignment was completed. Two to three answers would be posted for each assignment, to demonstrate to the students that answers which met the marking criteria for Synthesis (Table 1) were typically written quite differently and may have focused on different points. Showing alternative approaches to the same problem was intended to help shift students from procedural thinking (with one 'correct' approach) to conceptual thinking (different ways to approach a problem).

Methods

We conducted two studies to explore students' experiences with the Concept Question assignments and understand the realised learning outcomes of these assignments. One study used student reflections and course grades to assess learning (RQ1 and RQ2), and the second used a survey to explore students' perspectives on these assignments after completing the courses (RQ3). Both studies were approved by the University's Engineering, Architecture and Information Technology, Low and Negligible Risk Ethics Subcommittee (Project # 2017001656).

Table 2. Participant summary.

Course	Year	Student year level	No. of CQ assignments	Each CQ % of final grade	Total students	Students w/Reflections
Intro to environmental engineering	2016	> = 2	6	2.5%	46	42
Intro to environmental engineering	2017	> = 2	6	2.5%	45	41
Heat & Mass transfer	2016	> = 3	5	2%	204	108
Heat & Mass transfer	2017	> = 3	5	2%	199	117
Coastal & Estuary Processes	2017	> = 4	5	0%	11	4
TOTAL					505	312

Study 1: Courses with Concept Question assignments

In the first study, we used both qualitative and quantitative methods to explore student learning in courses where Concept Question assignments were used. We used qualitative methods to analyse student reflections on learning outcomes to address RQ1 and quantitative methods to understand relationships between Concept Question assignments and final exam grades to address RQ2.

Participants

This study analysed data from three courses in which concept questions were included as an assignment across multiple years. Table 2 summarises the sample of students whose grades and reflections were used in this analysis. Note that not all students submitted a final reflection, which is why there are fewer students in that column. The students in these courses range from first to fourth year of study, but a majority of participants were enrolled in Heat and Mass Transfer, which is compulsory course for third year by chemical engineering students. Intro to Environmental Engineering is a second-year course for chemical-environmental engineering students, but approximately half the students enrolled are in third year or above, and many are taking the course as an elective. Coastal and Estuary Processes is a fourth-year advanced elective for civil-environmental engineering students.

Data collection

The quantitative data for this study includes students' grades on the Concept Question assignments (both first and second attempts) and their final exam scores in the course. The qualitative data come from the final Concept Question assignment in each course, which was a reflection on learning in the course as a whole. The prompt for this assignment was:

> Part 1: What is something valuable you learned in [Course Name]? You may refer to skills, concepts, content, perspective, way of thinking etc. If you didn't learn anything valuable, explain why.
>
> Part 2: Explain how one or more learning activities affected your learning.

In response to these questions, most students wrote two to three paragraphs, although some students wrote less and some students wrote more. Students generally mentioned multiple learning outcomes and multiple learning activities in their responses.

Data analysis

To address RQ1, we used concept coding to characterise the learning outcomes students described in the student reflections. Concept coding assigns a code to a portion of text to summarise the larger idea or concept being described. We chose concept coding as an approach within this study, because we were analysing fairly long written pieces and wanted to assign codes that harmonised the bigger picture of what students were saying rather than focusing on smaller details (Saldaña 2013). We started with a smaller sample of 30 reflections that were used to generate the concept codes and then all 312 reflections were coded with the final codebook. The coding itself was conducted by one researcher, but the concept codes and coding process were reviewed iteratively by the larger research team, including both educational researchers and instructors from the relevant courses. Team discussions supported the development and refinement of codes and their associated descriptions (provided in the Results section). Throughout the process, the researcher conducting the analysis kept a clear audit trail of research decisions and team discussions (Leydens, Moskal, and Pavelich 2004).

To address RQ2, we used correlation analysis to investigate relationships between students' performance on the Concept Questions and their final exam score in the course. We note that although the final exams in these courses did not include Concept Questions in the format used in the assignments, all the exams required conceptual thinking because students were required to interpret the significance, meaning and/or implications of the results of their calculations. We considered scores on the Concept Questions, number of attempts, and changes in scores between attempts. Correlation analysis was the logical choice for this study because we were not using an experimental design and therefore can make no causal claims about our results (Shadish, Cook, and Campbell 2002).

Study 2: Student survey post-course

In the second study, we explored student approaches to learning engineering content by administering a survey to students who had taken courses that used Concept Question assignments (i.e., the same courses from Study 1). We focused on students' open-ended survey responses to explore research question three because they provided more insights into the unique approaches used across the survey participants. Open-ended questions risk a lack of detail if participants are unfamiliar or uncomfortable with a topic, but because these questions were about familiar and non-controversial topics, we expected that students would be able to write about them easily (Singleton & Straits 2009). The survey also included a series of closed-ended questions related to student processes for learning (based on work by Venters 2014) and knowledge resulting from reflection (survey developed by Turns et al. 2017). We do not report on these results here because of space restrictions and the higher relative usefulness of the open-ended responses. However, in designing the survey, we worked to order the topics in a way that flowed from more general topics (e.g., approaches to engineering coursework) to more specific topics (e.g., concept question assignments) to reduce bias in the students' responses (Singleton& Straits 2009).

Participants

The survey was sent to all students who had taken the courses listed in Table 1 ($n = 505$). The survey was sent in August 2018, so 8–24 months had elapsed since students had taken the course with Concept Questions. A total of 75 responses were received for a 15% response rate, which is a comparable to other studies in engineering education (e.g., Lattuca et al. 2017). Of the survey respondents, 45 students had taken one Concept Question course, and 30 students had taken two Concept Question courses. With approval by the ethics board at the university, a raffle for a $100 gift card was held to encourage student responses to the survey invitation.

Data collection

The survey included four open-ended questions aimed at understanding how students approached learning engineering concepts and what they learned from the Concept Question assignments. The questions were:

(1) What do you do to learn the content in your engineering courses beyond going to classes?
(2) What does your process look like for solving engineering tutorial problems? What steps do you typically follow? What resources do you use?
(3) What, if anything, did you feel you learned from the Concept Question assignments?
(4) How, if at all, did the Concept Question assignments lead you to change your study habits?

Most respondents included a response for each of these questions, and most responses were one to two sentences in length (although a few were longer).

Data analysis

In vivo coding was initially used in reviewing the students' open-ended responses to identify 'key phrases' that students used in response to each question (Strauss 1987). This coding approach uses words directly from the participants' responses as codes to describe the main concepts of interest (Saldaña 2013). We selected this approach for this study because we wanted to focus on the students' perceptions of their experiences in their courses. For each question, these phrases were then consolidated to a short list that captured the most common responses. All responses for the question were then coded for those key phrases, and we calculated the percentage of responses where each topic was discussed. Similar to Study 1, one researcher conducted the analysis, but the coding was reviewed and refined through discussions with the larger research team.

Limitations

These studies explore student experiences and outcomes with Concept Question assignments within a limited context. Because all student participants are from one university and mostly within one department, these results may not generalise to other contexts. Further, it is important to note that we cannot claim a causal relationship between the Concept Question assignments and the measured academic outcomes. There are many factors that could influence students' exam scores, so we are only able to look at correlations between these variables. Our results are also limited by the students who self-selected to take the survey. Although the raffle may encourage more students to complete such a survey, it is also possible that those who choose to participate are those who had particularly positive or negative experiences with Concept Questions. Students participating in the survey also varied in the length of time that had passed since they completed a course with Concept Question assignments. This may have resulted in differences in their responses based on their ability to remember their experiences with these assignments.

Results

In this section we first report the results from the analysis of student reflections (RQ1; Study 1), then the quantitative results from the grades analysis (RQ2; Study 1), and lastly the results of the survey of students who had taken courses that used Concept Questions (RQ3; Study 2).

RQ 1: Student reflection results (study 1)

We coded the final Concept Question reflections to identify themes in the topics that students discussed learning about in their courses. These reflections focused on learning outcomes of the course as a whole, but many students ($n = 215$, 69%) also discussed the Concept Question assignments specifically. Out of the 312 students whose reflections were coded, 74% ($n = 230$) included at least some technical course content in their reflection on what they learned, but 79% ($n = 246$) of students who completed the reflection assignment listed at least one other learning outcome. Table 3 lists the codes we identified along with the definition and frequency for each. Descriptions of the codes with representative quotes are included in the following sections.

Several of the learning outcomes that were intended through the use of the Concept Questions assignment were identified by students in their final reflections. *Problem Solving* was a common code for when students stated they had improved in their ability to solve engineering problems or had developed new approaches to solving problems. Specifically, students discussed learning new ways of defining problems, using diagrams or charts to solve problems, and being able to apply mathematical modelling to open-ended or 'wicked' problems. For example, one student said:

> Something valuable I learned in this course is to tackle engineering problems. The problem-solving approach taught in this course is drawing a diagram, listing assumptions, and listing relevant equations before solving for a value [...] Laying everything out in a succinct order meant I was able to understand the problem in depth, which resulted in finding a correct solution. This problem-solving approach not only helped me understand the content of this course, but I have used this method in other courses.

Communication was another desired learning outcome that was frequently mentioned in students' reflections. This code captured students' comments about improvement in their written, oral, or visual communication skills and statements about having a better understanding of how

Table 3. Codes in student reflections.

Code	Frequency	Definition
Technical content	230	Students describe specific technical concepts or skills that they learned from the course.
Applying concepts in a real-world context	97	Students state that they have a better understanding of how engineering concepts apply in real world examples.
Problem solving	73	Students state that they have improved in solving problems, developed a new way of solving problems, or describe having learned about 'wicked problems' and the complications associated with addressing these issues.
Communication skills	62	Students state that at least one of their communication skills (written, oral, visual) improved as a result of the course or that they have a clearer understanding of how communication is important in engineering work.
Personal or career development	38	Students describe a personal change as a result of the course, including changes in self-confidence, interest in a topic, motivation in their academic work, career goals, personal behaviour, or their mindset in approaching engineering courses.
Economics / financial influences on engineering	35	Students describe learning about financial or economic influences on engineering projects and/or how to do valuation analyses.
Learned about the field of engineering	26	Students state that they have a different perspective on a specific field of engineering or on engineering as a whole. This change could be a shift in viewing the role of engineers, what engineering work looks like, or what jobs are available to engineering graduates.
Systems thinking / multidisciplinary skills	26	Students state that they have learned to look at issues from a systems or multidisciplinary perspective, including considering the various stakeholders or perspectives that can influence a problem (e.g., economic, social, political).
Writing skills	23	Students specifically state that their writing skills have improved as a result of the course *(also coded as Communication, but listed separately because it was a goal of the CQ assignments).*
Critical thinking	22	Students state that they have learned how to think through an issue from multiple perspectives and challenge their own ideas.
Time management	12	Students state that they learned to manage their time better as a result of the course.

communication is important in engineering work. Students talked about learning what needs to be communicated in different settings or with different audiences. One student put it this way:

> The fortnightly concept questions encouraged me to practice the skills of communication and problem solving. I learnt to be more concise in my communications and the importance of having a well-structured response. […] The extra week to resubmit the submission after mentor feedback was also a great idea and I found my feedback very insightful and clear, which allowed me to improve my writing skills.

Systems Thinking and *Critical Thinking* were related codes that highlighted students' abilities to think about problems from multiple perspectives. *Systems Thinking* specifically focused on multidisciplinary approaches to problems and acknowledgement of social, political, or other 'non-technical' influences on technical problems. *Critical Thinking* focused on students' willingness to think about an issue from multiple perspectives and challenge their own ideas. This code includes learning reflective thinking and metacognitive skills. For example, one student described it this way:

> I have been challenged in the way that I think. […] Metacognition is a concept that I learnt a lot about through high school, but never found the need to apply it until this course. In the content, concept questions, and even the final assignment there was a lot of open-ended questions meaning there was no one correct answer. This resulted in me needing to think about what it was I was thinking about, or as was said above, metacognition. Often, I found that with many solutions to a question that my answers were often jumbled with multiple key points. Clarity was also often lacking. I would tangent and attempt to offer more than one solution to the questions where I should have focused on exploring one in depth.

In addition to these intended outcomes from the Concept Question assignments, there were several additional topics that students discussed in their reflections. The *Personal Change* code captured a wide array of student comments about how they had changed as a result of the course. These ranged from development of self-confidence, interest in a new topic, motivation toward their academic work, and specific career goals. Several students also described how the courses in the study had changed their mindset or approach to engineering courses that they hoped would help in future coursework. For example, one student said:

> [Course Name] taught me that perseverance pays off, especially through the concept questions. By reviewing concepts every week, it sticks without me even realizing it. It has also taught me that wild guesses can sometimes be right, and other times may just be nonsense. But the concepts are more burned in when I learn from mistakes that I have done in the past.

Similarly, the *Field of Engineering* code captured students' comments about how these courses provided different perspectives on a specific field of engineering or engineering as a whole. This code included the development of a clearer idea of the role of engineers in the workplace or what types of jobs are available to engineering graduates. One student described in this way:

> Prior to [Course Name], I'd thought that the only things that chemical engineers do were to optimize the processes to maximize profit and efficiency. However, […] I have realized that putting a proposal into a story is an important part of being a successful engineer. Although it is easy to do calculations and determine the best outcome, convincing stakeholders on why it's an appropriate plan is a tougher feat.

Overall, students described a wide range of learning outcomes from the courses included in this study. Not all outcomes directly linked to the Concept Question assignment, but many students referenced these assignments specifically in their reflections. Although a majority of students described learning the technical content associated with the course, most students also highlighted other learning outcomes.

RQ 2: Concept questions and grades analysis (study 1)

To see if there were any relationships between students' work on Concept Question assignments and their overall success in the course, we ran correlation analyses between both Final Exam grades and a variety of variables related to concept question responses (Table 4). Because we made multiple comparisons, we adjusted *p*-values for family-wise error rate using the Holm correction (Field, Miles, and Field 2012). Students were given two attempts at each Concept Question, so we considered both their average scores on 1st Attempts and Final score. To find out if using the second attempt option was beneficial, we also considered the number of attempts students made over the course of the semester (Total CQ Attempts), the number of Concept Question assignments for which they made a second attempt, and the average difference in their scores between the first and second attempts.

Table 4. Correlation results – Final exam grades.

Comparison variable	DF	Pearson r	*p*-value	R^2
Average Final CQ Score	503	<u>0.391</u>	<.001	0.153
Average Score 1st Attempt	503	<u>0.330</u>	<.001	0.109
# CQ with at least 1 Attempt	503	0.206	<.001	0.043
# CQ with 2 Attempts	503	0.251	<.001	0.063
Total CQ Attempts	503	0.269	<.001	0.072
Average Difference 1st to 2nd	503	0.184	.004	0.034
CQ1 – Final Score	503	0.280	<.001	0.079
CQ2 – Final Score	503	0.230	<.001	0.053
CQ3 – Final Score	503	<u>0.328</u>	<.001	0.108
CQ4 – Final Score	503	<u>0.340</u>	<.001	0.116
CQ5 – Final Score	503	<u>0.323</u>	<.001	0.104
Program GPA	503	**0.563**	<.001	0.316

Note: CQ = Concept Question. Bold text = strong correlation. Underlined text = medium correlation.

Although all of the variables significantly correlated with students' final exam grades, most the variables exhibit only a weak correlation ($0.1 < r < 0.3$). Five of the 11 Concept Question variables achieve a medium correlation ($0.3 < r < 0.5$), *Average Final CQ Score*, *Average Score 1st Attempt*, and the *Final Scores on CQ3–5*. The R^2 value indicates the amount of variability shared between these variables and the Final Exam Grades, revealing around 10% in common for these five variables. Only one variable exhibits a strong correlation ($r > 0.5$), *Program GPA*, which shares 31% variability with the final exam grade.

In summary, the *scores* on the concept questions have a greater correlation with the final exam grade than *attempts*. This observation suggests that performing well on concept question assignments related to performing better on the final exam. Although attempting concept questions may help toward that end, the attempts alone are less related to final exam performance. This finding could indicate that students who perform well on Concept Question assignments have a better understanding of the material that is needed to be successful on the exams. It is notable that the scores on the *final 3 concept questions* relate more closely to final exam grades than the scores on the first two concept questions. This finding may relate to student comfort with the course content increasing over time or their increasing familiarity with the Concept Question assignments and expectations. It also could indicate that students began utilising the concept question assignments more fully later in the semester, or perhaps suggests that the more motivated students are the ones who stayed engaged until the end of the semester. Lastly, students' *program GPA* is the most closely related to their final exam score, indicating that students who do well in the engineering programme overall tend to do well on the final exams in these courses. This effect is much stronger than any effect of the concept questions. The marks on CQ3, 4, 5 are also strongly correlated with GPA, but the marks for CQ1 and CQ2 are not. This is consistent with the observations of the teaching staff: the Concept Question assignments required students to develop their critical thinking and communication as well as learning the course content. As a result, most students received low marks for the first few questions. As the students developed the requisite skills and gained an appreciation of what constitutes an excellent answer, the correlation between Concept Question assignment marks and GPA was established.

RQ 3: Student survey (study 2)

Reading students' responses to the Concept Question reflections gave some insight into their learning strategies. In particular, we were curious about whether students typically used a more procedural or conceptual learning approach. To explore students' learning approaches in more detail, we conducted a survey of students who had taken courses with Concept Question assignments to understand their typical approaches to learning within their engineering courses. Here we report the results of four open-ended questions from this survey that gave useful insights regarding student learning approaches and their experiences with the Concept Question assignments.

Student learning approaches

The first two questions explored student approaches to learning by asking students to describe what they do to learn course content and to solve engineering tutorial problems. Figure 1 shows the most common responses for Question 1, and Figure 2 shows the most common responses for Question 2.

Question 1 asked students to reflect on their preferred approaches to learning engineering course content aside from attending classes. The responses to Question 1 revealed that many students prefer tutorial material to lecture material for learning course content. Tutorial materials typically consist of practice problems without much explanation related to concepts, suggesting that these students may be using a more procedural approach to learning (i.e., repetitively practicing problems). It is also notable that students are more likely to consult classmates, textbooks, and the internet before consulting teaching staff. The instructors for these courses have observed this behaviour and find that it can encourage incorrect information to spread, particularly when students are not

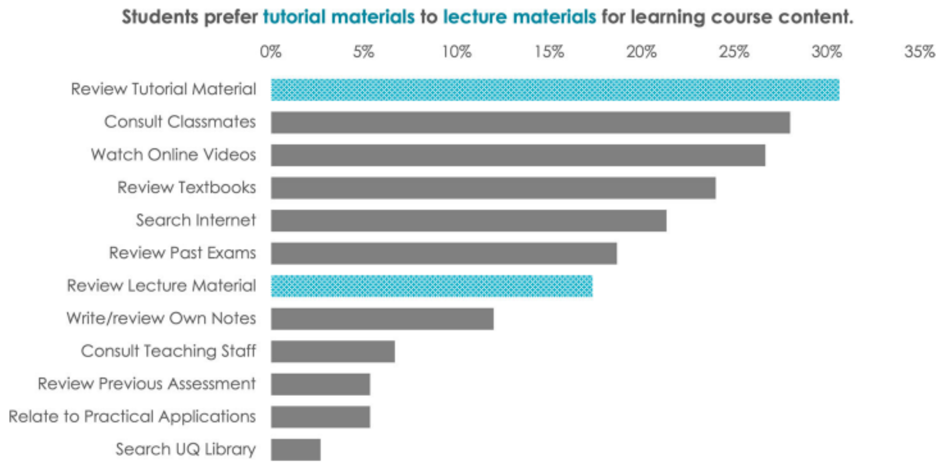

Figure 1. Most Common Responses to Question 1: What do you do to learn the content in your engineering courses beyond going to classes? ($n = 75$).

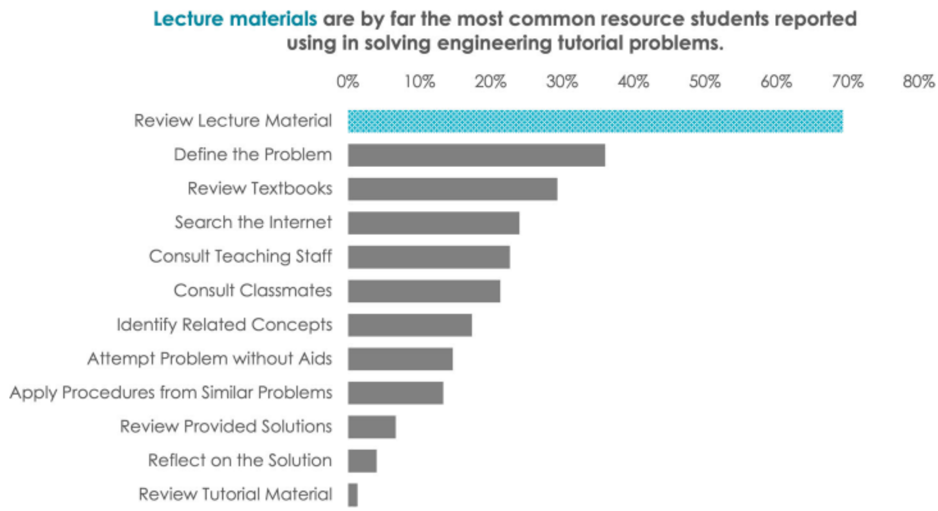

Figure 2. Most Common Responses to Question 2: What does your process look like for solving engineering tutorial problems? What steps do you typically follow? ($n = 75$).

sure why a certain approach works. Lacking conceptual understanding, students may simply try to find a process to get the 'right answer.' Finally, it is important to note the relatively few students who reference their own notes to learn course content. The instructors also have found that few students write their own notes, either tending only to review the slides or copy slide content during a lecture. Taking notes, reviewing them, and condensing them can be an important part of the learning process, so this finding highlights a potential area for helping students improve their study habits.

Question 2 asked students to consider their approaches in solving engineering tutorial problems, a regular aspect of engineering coursework. In contrast to Question 1, students suggested that they prefer to use lecture material to help solve tutorial problems. In fact, the large majority of students mentioned using lecture material in problem solving in response to this question. Students were also more likely to consult teaching staff in the specific context of solving tutorial problems compared to generally learning course content. Solving tutorial problems could be interpreted as a more procedural task than learning course content overall (from Question 1). Perhaps in this context where

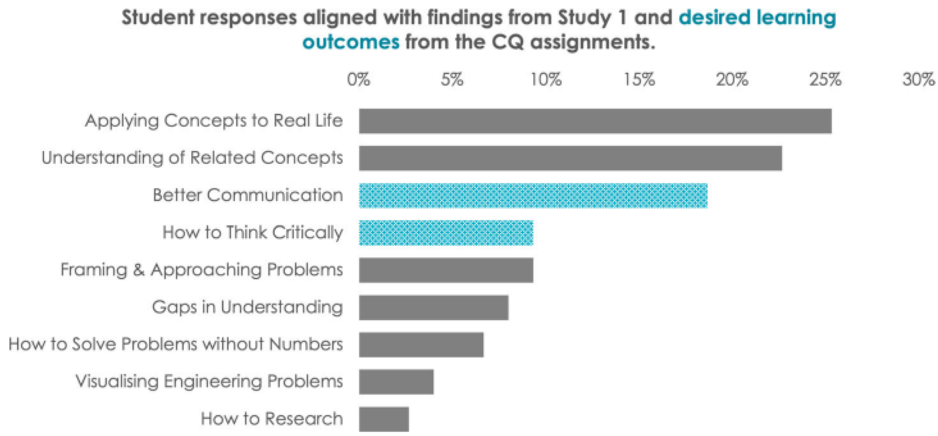

Figure 3. Most common responses to Question 3: What did you feel you learned from the Concept Question assignments? (n = 75).

there is a specific question to be addressed, students feel more comfortable looking for relevant topics in their lecture material or approaching teaching staff with a specific question. The observation that these students didn't find value in reviewing previous tutorials in tackling current tutorials may suggest that the tutorials in their courses dealt with compartmentalised topics, rather than integrating content from previous weeks.

Student responses to Concept Questions

The next two questions asked students to describe what they learned from the Concept Question assignments and how these assignments influenced their study habits. Figure 3 shows the most common responses to Question 3, and Figure 4 shows the most common responses to Question 4.

Question 3 sought to understand how students' perspectives on the Concept Question assignments may have shifted between taking the courses that included these assignments and the

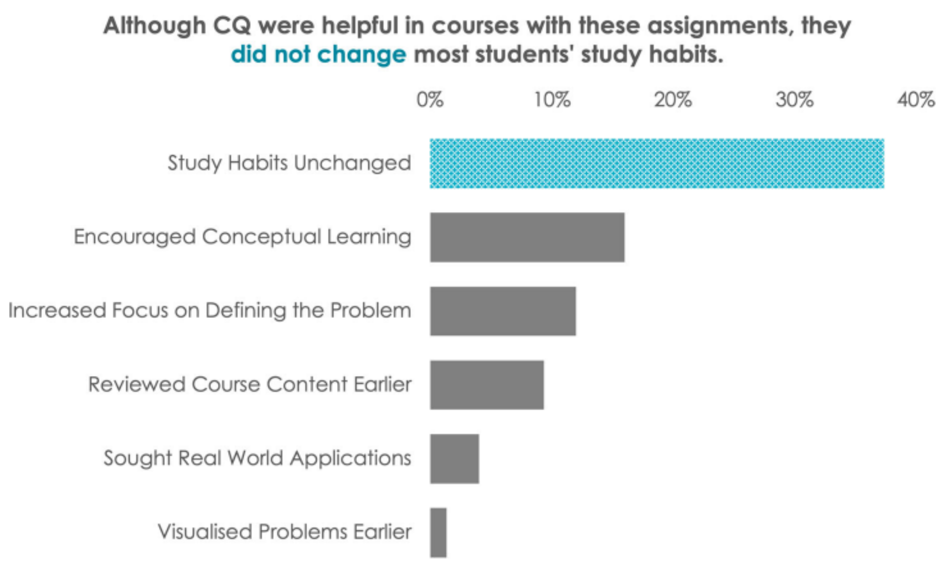

Figure 4. Most common responses to Question 4: How, if at all, did the Concept Question assignments lead you to change your study habits? (n = 75).

survey administration (a few months or years later). Overall, the responses aligned with the learning outcomes discussed by students in their course reflections from Study 1. In particular, many students focused on learning real-life application of the concepts and the engineering-related concepts associated with the course. However, many also mentioned communication and critical thinking, which were two of the key learning outcomes that were targeted by the Concept Question assignments. Some new insights from this survey are that, rather than discussing problem solving more generally, students discussed specific aspects of problem solving such as framing problems and visualising engineering problems. Overall, most students described learning something specific from the Concept Question assignments.

Given the various learning outcomes students listed in Study 1 for the Concept Question assignments, we wanted to know if they had carried any of these new approaches over into their other classes. Thus, Question 4 asked students how the Concept Question assignments may have changed their study habits. Contrary to our hopes, a majority of students stated that their study habits were not influenced by the Concept Question assignments. A minority of students did feel that they were more likely to focus on learning concepts and others approached problems differently as a result of the Concept Question assignments.

Discussion

Our study explored the implementation of a Concept Question assignment in multiple upper-level engineering courses. We first considered students' perceived learning outcomes from this assignment, which included both the technical content of the courses as well as several of the other learning outcomes desired through this assignment (e.g., communication skills and critical thinking). Most students described learning outcomes beyond the technical content of the courses as a part of their final reflection on the course, and many referenced the Concept Question assignment as a contributing factor. These findings align with the results of prior studies, which have suggested that writing or conceptual understanding assignments like the Concept Question assignment help students develop critical thinking and communication skills (Hanson and Williams 2008; Hermundstad et al. 2016; Meyer et al. 2015a, 2015b). The students in our study also mentioned other outcomes that have not been highlighted in previous more focused studies, including developing a better understanding of engineering as a field and being exposed to examples of how the concepts from the class actually play out in the 'real world.' These findings suggest that incorporating more assignments informed by situated learning theory into engineering courses could be an opportunity to help students see the meaning and purpose behind course content. Understanding the utility of the content has been highlighted as one way to improve student motivation in classrooms (Jones 2009).

We next explored whether students' performance on the Concept Question assignments related to their final exam scores in the courses. Students' average scores on the assignments significantly correlated with their final exam score with a medium-strength relationship. The Concept Question assignments later in the semester were more strongly correlated with the final exam score than those earlier in the semester, which may indicate that students who were continuing to put effort into the assignments throughout the semester performed better on the exam, or that marks on final exams depended less on their initial comfort with the Concept Questions, but rather their ability to learn and improve over time at a task. However, the variable that was most strongly correlated with final exam scores was GPA, suggesting that student performance in this class generally aligned with their performance across the engineering curriculum. Overall, these results provide some support for the idea that students' conceptual understanding of the course content (as measured by the Concept Questions) is related to their overall performance in the course. This finding provides an alternative perspective to the results from Venters, McNair, and Paretti's (2012) quasi-experimental study which found no relationship between students' completion of concept problems and their course performance. The earlier study did not look at the scores on the concept problems, however, but only considered whether or not a student enrolled in a course section using these assignments, so our study provides a new insight in this regard. Our findings were more aligned with Venters, McNair, and Paretti (2012) in that the number of attempted Concept Questions was only weakly correlated with students' final exam grades. Thus, simply going through the motions of the exercise did not have as strong of a relationship with course performance relative to success on the exercise. On the other hand, many students commented in their reflections that the opportunity to respond to feedback made the feedback more valuable for their learning. For example, one student said:

> Having the opportunity to receive feedback on concept questions and actually use this feedback to improve is something I would love other courses to adopt, as it gives a direct use for the feedback received. I have learned far more through this process than if I had just received the feedback without the opportunity to try again.

This strategy of giving students 'two takes' to improve the value of feedback for their learning is aligned with constructivist learning theory and represents an opportunity to help students develop a deep approach to learning (Biggs 2003). Exploring assignments following this format further is an opportunity for future research.

Lastly, we surveyed students who had taken courses using the Concept Question assignments to understand their approaches to learning engineering content. Our results indicated that students prefer tutorial materials (e.g., practice problems) over lecture materials (e.g., slides or notes) in learning engineering content. This result may suggest that students do not see how concepts build on each other throughout their courses, which has been identified as a challenge in engineering courses (Knight et al. 2014). These findings also reveal a preference for procedural learning approaches over more conceptual approaches. However, when asked how they approached tutorial problems, students frequently discussed using the lecture material as a resource. This pattern aligns with the interview results reported by Venters, McNair, and Paretti (2014), where many students discussed using practice problems as the most effective way to learn course content. Their results indicated that students fall on a range from procedural to conceptual approaches to learning, with many students near the 'balance' point on the continuum. These students were likely to reference textbooks and lecture notes to ensure that they understood concepts even as they were working on more procedural problem sets (Venters, McNair, and Paretti 2014). Our survey results also supported the earlier findings regarding student learning outcomes from the Concept Question assignments but indicated that students did not feel that their study habits changed as a result of these assignments. Thus, although the assignments seem to have benefitted students in the courses where they were embedded, this benefit may not have been carried over to other courses. This result aligns with Meyer et al.'s (2015b) findings that 50% of students in their study reported no change in their learning strategies as a result of a conceptual learning intervention. It is notable that in our study, students who had taken two courses with Concept Question assignments were more likely to say their study habits had changed. It is possible that incorporating these types of assignments across multiple courses would have a greater effect on student behaviour and learning. Future work could explore the impact of a more integrated approach to conceptual learning across the engineering curriculum.

Conclusion

Our study presented a longitudinal evaluation of a pedagogical intervention based in constructivist and situated learning theory to support conceptual learning in advanced engineering courses. Although students reported a wide range of learning outcomes from the Concept Question assignments and there was a relationship between the assignments and their final exam grades, most students did not report that their study habits changed in subsequent courses as a result of this intervention. Our findings provide a new perspective on the longitudinal effects (or lack thereof) of such interventions, suggesting that supporting students in developing deep learning approaches and conceptual learning habits requires a more integrated strategy across the curriculum. Overall, we provide an enhanced understanding of student approaches to learning in upper-level engineering courses.

Acknowledgements

Learning designer Esther Fink helped in the original application of these questions. Melanie Fleming assisted in the ethics application.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Note on contributors

Kirsten A. Davis is an assistant professor in the School of Engineering Education at Purdue University. Her research explores the intentional design and assessment of global engineering programs, student development through experiential learning, and approaches for teaching and assessing systems thinking skills. Kirsten holds a B.S. in Engineering & Management from Clarkson University and an M.A.Ed. in Higher Education, M.S. in Systems Engineering, and Ph.D. in Engineering Education, all from Virginia Tech.

William A. Mogg is a Chemical Engineer, an educator and a musician. Will is passionate about engineering education which delivers maximum value for students: challenging students with new ways thinking and seeing the world, encouraging conceptual rather than procedural learning, and motivating and engaging students in lifelong learning.

Dr. David P. Callaghan graduated from the Queensland University of Technology (BE Civil-Hons) in 1993 and The University of Queensland (PhD focusing on Coastal Engineering) in 2005. He commenced his professional career within structural, flooding and drainage engineering. Since 2006, David has been actively involved in coastal engineering research and now holds an academic position at The University of Queensland. His main interests includes extreme value beach erosion and flood levels for planning and development and how climate change impact these. He is part of a large group of applied researchers working to save the Great Barrier Reef and teaches from first year civil engineering to through capstone design in the natural environment.

Associate Professor Greg R. Birkett is an academic in the School of Chemical Engineering and Deputy Associate Dean in the Faculty of Engineering Architecture and IT at the University of Queensland. Greg is a Teaching and Research academic who works in applied and fundamental chemical engineering research, teaching leadership, and teaching innovation. His teaching ranges from large first year classes in thermodynamics to capstone Master's design courses. Dr Birkett's current interests include curriculum development, modelling, and mapping and the development of professional and transferrable skills across degrees.

David B. Knight is an Associate Professor in the Department of Engineering Education and Special Assistant to the Dean for Strategic Plan Implementation at Virginia Tech. He is also Director of Research of the Academy for Global Engineering at Virginia Tech and is affiliate faculty with the Higher Education Program. His research tends to be at the macro-scale, focused on a systems-level perspective of how engineering education can become more effective, efficient, and inclusive, tends to leverage large-scale institutional, state, or national data sets, and considers the intersection between policy and organizational contexts. He has B.S., M.S., and M.U.E.P. degrees from the University of Virginia and a Ph.D. in Higher Education from Pennsylvania State University.

Associated Professor Katherine R. O'Brien (BE Chemical Hons I, BSc, PhD) is Director of Teaching and Learning in the School of Chemical Engineering at the University of Queensland. Kate leads the chemical-environmental engineering program, and applies mathematical modelling in to bridge gaps between disciplines in teams tackling sustainability problems. Kate is passionate about finding and sharing practical, effective methods to teach engineering students the skills needed to tackle unsustainable practices and other complex, open-ended problems: critical thinking, systems thinking, strategic thinking, creativity, effective teamwork and communication.

ORCID

Kirsten A. Davis http://orcid.org/0000-0002-9929-5587
David P. Callaghan http://orcid.org/0000-0003-1405-7510
Greg R. Birkett http://orcid.org/0000-0001-5428-5628
David B. Knight http://orcid.org/0000-0003-4576-2490
Katherine R. O'Brien http://orcid.org/0000-0001-8972-9161

References

Biggs, J. B. 1985. “The Role of Metalearning in Study Processes.” *British Journal of Educational Psychology* 55 (3): 185–212.

Biggs, J. B. 1993. “From Theory to Practice: A Cognitive Systems Approach.” *Higher Education Research and Development* 12 (1): 73–85. doi:10.1080/0729436930120107.

Biggs, J. B. 2003. *Teaching for Quality Learning at University* (2nd ed.). Open University Press.

Bornasal, F., S. Brown, N. Perova-Mello, and K. D. Beddoes. 2018. “Conceptual Growth in Engineering Practice.” *Journal of Engineering Education* 107 (2): 318–348. doi:10.1002/jee.20196.

Bransford, J. D., A. L. Brown, and R. R. Cocking, eds. 2000. *How People Learn: Brain, Mind, Experience, and School.* Washington, DC: National Academy Press.

Field, A., J. Miles, and Z. Field. 2012. *Discovering Statistics Using R.* Los Angeles, CA: Sage Publications.

Goncher, A., C. Venters, W. Boles, D. Jayalath, L. D. McNair, and M. C. Paretti. 2015, December. *“Using Reflective Writing and Textual Explanations to Evaluate Students’ Conceptual Knowledge*.” Australasian association for engineering education 2015 conference, Geelong, Victoria, Australia.

Greeno, J. G., A. M. Collins, and L. B. Resnick. 1996. “Cognition and Learning.” In *Handbook of Educational Psychology*, edited by D. C. Berliner, and R. C. Calfee, 15–46. New York, NY: Simon & Schuster Macmillan.

Hanson, J. H., and J. M. Williams. 2008. “Using Writing Assignments to Improve Self-Assessment and Communication Skills in an Engineering Statics Course.” *Journal of Engineering Education* 97 (4): 515–529. doi:10.1002/j.2168-9830.2008.tb00997.x.

Hermundstad, A. L., T. E. Diller, C. B. Williams, and H. M. Matusovich. 2016, June. *“Exploring Conceptual Understanding in Heat Transfer: A Qualitative Analysis*.” 2016 ASEE Annual Conference and Exposition, New Orleans, LA.

Johri, A., B. M. Olds, and K. O’Connor. 2014. “Situative Frameworks for Engineering Learning Research.” In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, 47–66. New York, NY: Cambridge University Press.

Jonassen, D. H. 2014. “Engineers as Problem Solvers.” In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, 103–118. New York, NY: Cambridge University Press.

Jones, B. D. 2009. “Motivating Students to Engage in Learning: The MUSIC Model of Academic Motivation.” *International Journal of Teaching and Learning in Higher Education* 21 (2): 272–285.

Knight, D. B., D. P. Callaghan, T. E. Baldock, and J. H. F. Meyer. 2014. “Identifying Threshold Concepts: Case Study of an Open Catchment Hydraulics Course.” *European Journal of Engineering Education* 39 (2): 125–142. doi:10.1080/03043797.2013.833175.

Krathwohl, D. R. 2002. “A Revision of Bloom’s Taxonomy: An Overview.” *Theory Into Practice* 41 (4): 212–218. doi:10.1207/s15430421tip4104_2.

Lattuca, L. R., D. B. Knight, H. K. Ro, and B. J. Novoselich. 2017. “Supporting the Development of Engineers’ Interdisciplinary Competence.” *Journal of Engineering Education* 106 (1): 71–97. doi:10.1002/jee.20155.

Leydens, J. A., B. M. Moskal, and M. J. Pavelich. 2004. “Qualitative Methods Used in the Assessment of Engineering Education.” *Journal of Engineering Education* 93 (1): 65–72. doi:10.1002/j.2168-9830.2004.tb00789.x.

Lord, S. M., and J. C. Chen. 2014. “Curriculum Design in the Middle Years.” In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, 181–199. New York, NY: Cambridge University Press.

Marton, F., and R. Säljö. 1976a. “On Qualitative Differences in Learning: I - outcome and Process.” *British Journal of Educational Psychology* 46 (1): 4–11. doi:10.1111/j.2044-8279.1976.tb02980.x.

Marton, F., and R. Säljö. 1976b. “On Qualitative Differences in Learning: II - outcome as a Function of the Learner’s Conception of the Task.” *British Journal of Educational Psychology* 46 (2): 115–127. doi:10.1111/j.2044-8279.1976.tb02304.x.

Meyer, J. H. F., D. B. Knight, D. P. Callaghan, and T. E. Baldock. 2015a. “An Empirical Exploration of Metacognitive Assessment Activities in a Third-Year Civil Engineering Hydraulics Course.” *European Journal of Engineering Education* 40 (3): 309–327. doi:10.1080/03043797.2014.960367.

Meyer, J. H. F., D. B. Knight, D. P. Callaghan, and T. E. Baldock. 2015b. “Threshold Concepts as a Focus for Metalearning Activity: Application of a Research-Developed Mechanism in Undergraduate Engineering.” *Innovations in Education and Teaching International* 52 (3): 277–289. doi:10.1080/14703297.2015.1017515.

Newstetter, W. C., and M. D. Svinicki. 2014. “Learning Theories for Engineering Education Practice.” In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, 29–46. New York, NY: Cambridge University Press.

Paul, R., and L. Elder. 2006. *The Miniature Guide to Critical Thinking Concepts and Tools*. Santa Rosa, CA: Foundation for Critical Thinking.

Saldaña, J. 2013. *The Coding Manual for Qualitative Researchers* (2nd ed.). Thousand Oaks, CA: SAGE Publications.

Shadish, W. R., T. D. Cook, and D. T. Campbell. 2002. *Experimental and Quasi-Experimental Designs for Generalized Causal Inference*. Boston, MA: Houghton Mifflin.

Singleton, R. A., and B. C. Straits. 2009. *Approaches to Social Research* (5th ed.). New York, NY: Oxford University Press.

Strauss, A. L. 1987. *Qualitative Analysis for Social Scientists*. London, England: Cambridge University Press.

Streveler, R. A., S. Brown, G. L. Herman, and D. Montfort. 2014. "Conceptual Change and Misconceptions in Engineering Education: Curriculum, Measurement, and Theory-Focused Approaches." In *Cambridge Handbook of Engineering Education Research*, edited by A. Johri, and B. M. Olds, 83–101. New York, NY: Cambridge University Press.

Streveler, R. A., T. A. Litzinger, R. L. Miller, and P. S. Steif. 2008. "Learning Conceptual Knowledge in the Engineering Sciences: Overview and Future Research Directions." *Journal of Engineering Education* 97 (3): 279–294. doi:10.1002/j.2168-9830.2008.tb00979.x.

Turns, J., K. E. Shroyer, T. L. Lovins, and C. J. Atman. 2017, June. "*Understanding Reflection Activities Broadly*." 2017 ASEE Annual Conference and exposition, Columbus, OH.

Venters, C. 2014. *Using Writing Assignments to Promote Conceptual Knowledge Development in Engineering Statics*. Blacksburg, VA: Virginia Tech.

Venters, C., L. D. McNair, and M. C. Paretti. 2012, June. "*Using Writing Assignments to Improve Conceptual Understanding in Statics: Results from a Pilot Study*." 2012 ASEE Annual Conference and exposition, San Antonio, TX.

Venters, C., L. D. McNair, and M. C. Paretti. 2013, June. "*Using Writing to Link Procedures and Concepts in Statics*." 2013 ASEE Annual Conference and exposition, Atlanta, GA.

Venters, C., L. D. McNair, and M. C. Paretti. 2014, October. "*Writing and Conceptual Knowledge in Statics: Does Learning Approach Matter?*" 2014 IEEE frontiers in Education conference, Madrid, Spain.

Appendices

Appendix A: Sample Concept Question Answers

Below are sample answers provided to students in Heat and Mass Transfer, along with the marking criteria in Table 1, prior to them undertaking the concept question assignments. Final submissions were longer than these simple answers.

Example Question: *The bottom of a saucepan is made of a 4 mm aluminum layer. An engineer proposes to increase the rate of heat transfer into the saucepan by changing to a 4 mm layer of copper sandwiched between two 2 mm layers of aluminum. Will the new design conduct heat better? Explain your answer.*

0 – No submission, or no correct information
Example answer:

- *The new design will conduct heat better.*

The answer above is graded 0 because it does not contain any correct information.

2 – Limited correct information.
Example answers:

- *The new design will conduct heat better, because copper is a better conductor.*
- *The new design is better, because copper has a higher thermal conductivity than aluminum.*

The answers above are graded 2 because they have very limited information, some of which is correct. The use of the term 'better' here is imprecise: better at what?

4 – Observational: Response contains simple observations with correct information. No connections are made between different components of the problem OR some connections correctly made but response contains significant errors. Wording may be ambiguous.
Example answers:

- *The new design will not conduct heat as well as the old design.*
- *The new design will conduct heat better, because copper has a higher thermal conductivity than aluminum.*

The answers above are graded 4: the first answer is correct but very limited, the second answer contains a mix of correct and incorrect information.

6 – Analysis: Important connections between different aspects of the problem are clearly identified and explained. There may be minor errors or wording may lack precision.
Example answers:

- *The new design will not conduct heat as well as the old design, because the new base has higher thermal resistance.*
- *The old design will conduct heat better, because the new design has an extra layer of resistance.*

- *The thickness of aluminum is the same in both designs, but the new design has an extra layer of resistance, therefore won't conduct heat as well.*
- *The old design is better, because it has a lower resistance to conduction. There is an extra resistance in the new design.*

The answers above are graded 6 because they provide clear, correct answers to the problem, drawing connections between important information, but don't provide more general insights. The use of the term 'better' in the second point is imprecise: better at what? A much longer paragraph with some variation on the information as above and no real additional content would receive the same mark.

8 – Synthesis: question answered with no errors, drawing connections between different aspects of the problem. The answer provides information concisely and precisely, and the significance of the answer beyond this specific problem is clear.
Example answers:

- *Even though the thermal conductivity of copper is more than 50% higher than that of aluminum, the new design will not conduct heat as well as the old design. This is because the new design has the same thickness of aluminum as the old design but contains an additional resistance (the extra layer of copper), and hence has a higher resistance to heat transfer. Adding a high thermal conductivity material to the design will only increase the rate of heat transfer if the overall resistance is reduced: in this case, the thickness of the aluminum would need to be reduced for the second design to be a better conductor.*

The answer above is graded 8 because it provides clear, correct information in a precise and concise format, which draws connections and answers the specific question in a way which helps the reader solve other, similar problems. Alternative responses which would also be graded 8 could include a similar explanation using the equations for overall heat transfer coefficient and resistance, calculation of the thickness of copper with equivalent thermal resistance to 4 mm of aluminum, a comment on how a thicker base might benefit other aspects of the saucepan design, (e.g., even heating across the base), or other relevant points.

Appendix B: Concept Questions Assigned

Concept questions provided to Heat and Mass Transfer in 2016

Concept Question 1

Consider two houses which are identical, except that the walls are built from bricks in one house, and from wood in the other house. If the walls of the brick house are twice as thick as the walls of the wooden house, which house will be more energy efficient? Explain your answer.

Concept Question 2

Consider a typical scenario of making a cup of tea with teabag. Explain the principles of heat and mass transfer involved. Also, compare the shallow submergence and the deep submergence of the teabag into the hot water. Which one makes the process of the tea-making faster? and why?

Concept Question 3

I have a beautiful piece of barramundi in the freezer, I've been saving it specially for a special dinner tonight. However, I forgot to take it out of the freezer, and it is now midday. My guests are due at 7 pm. I can defrost it in the microwave, but that seems to adversely affect the texture and flavour. I rang my Dad, and he suggested that I leave it on the bench to defrost. Mum got on the phone after him, she says it's more likely to give someone food poisoning if I defrost it on the bench. She suggested that I put it in a bowl of water in the fridge. The fridge is at 4°C, the barramundi fillets weigh 1 kg and are currently frozen at −20°C, the outside air temperature is 30°C. I know that I should minimise the time spent on defrosting at a temperature between 6 and 60°C in order to reduce chance of bacterial contamination. What should I do? (Hint: remember there will be natural convection in the cases suggested by my Mum and my Dad)

Concept Question 4

Consider small spherical peaches (diameter 2 cm), initially at a uniform temperature of 20°C. The peaches need to be cooked at 100°C for 2 h for preserving. They can be cooked in a conventional oven ($h \sim 10\ Wm^{-2}K^{-1}$, $T_\infty \sim 100$°C), stewed ($h \sim 100\ Wm^{-2}K^{-1}$, $T_\infty \sim 100$°C) or boiled ($h \sim 1000\ Wm^{-2}K^{-1}$, $T_\infty \sim 100$°C). How will the different cooking methods affect the temperature distribution of the peaches, and the cooking time? (Note: both stewing and boiling involve cooking the peaches in water in a saucepan. Boiling has an open lid, and the water is actively boiled. Stewed peaches are in a saucepan with the lid on, which is not actively boiling)

Concept Question 5

Humans typically generate around 100 W of heat during low activity, and around 1 kW at high activity. Despite this large variability in heat generation, a complex system of thermoregulation keeps our body temperature relatively constant at 37°C. However sometimes things go wrong. If the rate of heat loss from the body is less than the rate of generation, then body temperature will rise. Heat exhaustion occurs when body temperature is above 37°C, but less than 40°C. Heat stroke is a potentially life-threatening condition which occurs when body temperature rises above 40°C.

When exercising in the hot and humid conditions of a Brisbane summer, what precautions do you recommend to reduce the risk of heat exhaustion or heat stroke? Explain your answer using the principles of heat and mass transfer learnt in this course.

Concept Question 6

1. What is something valuable you learned in this course? You may refer to skills, concepts, content etc. If you didn't learn anything valuable, explain why.
2. Explain how one or more learning activities (e.g., field trip, assignments, prac, concept questions, lectures, tutorials) affected your learning.