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Identifying threshold concepts in final year engineering projects

Stephen Kershaw[1], Stephen.Kershaw@open.ac.uk

Andrea Patel[2], Andrea.Patel@open.ac.uk

James Warren[3], James.Warren@open.ac.uk

[1] **Digital Services, Chief Data Office**

[2] **School of Engineering and Innovation**

[3] **Associate Dean, Student Experience, STEM Faculty**

Abstract

Threshold concepts (TC) are a key learning theory which can be applied to many subjects within STEM. This study considers TCs within the capstone engineering project at the Open University. Threshold concepts are concepts which require drastic reworking of one's own conceptual framework before crossing a threshold of understanding. Project tutors identified three major points where students appeared to struggle in their project work, or where students most often become stuck. These three points were then mapped against: previous attempts, assessment scores, predicted probability of success, and extensions on assignments (lateness). The findings include predicted probability values are good markers for success and can be mapped against many variables to demonstrate the presence of barrier to learning or thresholds. The study focuses on the first threshold where students get stuck on their initial project proposal in their first assignment. We observe late student submissions (34% of all) have lower marks (-9%) compared with those on time. Students with higher risk of failure in our predictive model also tend to have lower marks overall especially when they are late or have extensions on the first assignment.

Keywords: Threshold concept, engineering, capstone project, student success, predictive modelling, withdrawal rates, project proposal.

Introduction and Literature Review

The Engineering Project (T452) is a capstone learning experience for BEng Engineering students and a route for BA/BSc Design and Innovation students and Open degree students at the Open University. The module has grown in recent years, with the number of students studying T452 increasing from 260 students in 2018 to around 450 students in 2024. Whilst these students may be considered expert students, the module presents challenges that may include feelings of uncertainty and anxiety that occur during a period of transition as students move from more formal and structured taught modules to a module that requires greater autonomy. This change in learning style enables students to develop, demonstrate and integrate the knowledge, skills, and capabilities they have gained during their degree to a project that is individual to them. Transition is the psychological process of coming to terms with change, and whilst change can happen quickly (i.e., an abrupt change in learning style), transition by comparison can be slow and can be associated with a range of emotions. For example, students may be excited about their project, but they may also feel uncomfortable, uncertain and may begin to question their capabilities and may struggle due to lack of previous experience (Todd et al, 2004).

Meyer and Land (2003, 2006) introduced threshold concepts as concepts students must grasp to progress their learning and development, and that are associated with the following characteristics:

- Transformative: achieving threshold concepts is transformative because it changes how students understand, interpret, and perceive. Threshold concepts can be thought of as a portal that opens to allow access to a previously inaccessible way of thinking (Barradell, 2013).
- Irreversible: once a student has achieved a threshold concept, they are not able to forget it.
- Integrative: achieving a threshold concept allows a student to make connections that were previously hidden from them.
- Bounded: it is likely that the threshold concept will be bounded in a conceptual space e.g., a specific discipline.
- Troublesome knowledge: threshold concepts may feel uncomfortable and/or counter-intuitive to students.

Threshold concepts differ from core concepts in that core concepts build on previous foundations of learning (i.e., adding more layers) rather than meeting the above five characteristics identified for threshold concepts (Meyer and Land, 2003).

Prior to grasping a threshold concept, students will occupy a liminal space as students work towards grasping threshold concepts (Cousin, 2006). If students become stuck in this liminal space, they may feel unable to continue, lose confidence and question their identity. Identifying threshold concepts can help to inform curriculum by identifying key areas that need mastery, pinpointing common student misunderstandings and uncertainties and supporting tutors and curriculum design to support students through the liminal space (Barradell, 2013). Once the student grasps the new concept, they 'leave' the liminal space and cross the threshold described by Penprase (2020, p.46) as an ontological shift.

There is a gap in research into threshold concepts for undergraduate projects, with previous research focussing predominantly on taught curriculum and to a lesser extent doctoral education. Threshold concepts are a contested concept in themselves and some may argue that the key barriers that are identified here are too broad to be considered a 'proper' TC. Taylor (p.95, 2006) find that there are challenges in identifying true TCs and in general many TCs are embedded into their subject context (e.g. hypothesis testing in biology). This study assumes that whatever these barriers to learning are called is not critical; it is more important to understand from a project supervisors point of view and for the academics involved in supporting the students.

Our study focusses on the key question: **what are the key concepts that students struggle with in their final year project?** As part of the study a sub-objective emerges: is there evidence for a TC based around the student developing their independent project.

Methods

The capstone project tutors contributed informally to our study during our annual briefings held online at the start of each academic year. There are approximately 75 project tutors in the engineering discipline and about 65% of them contributed actively with many others agreeing about the main obstacles during our online sessions. We asked them what they felt students struggled most within project study and where students became stuck in their learning. They shared their experiences with us and then we played these back to them in a set of statements about each barriers. These barriers were then aligned with the project assignments and the general module weekly calendar.

The first major barrier was reported to be: scoping and choosing a feasible project (TC1). This paper focusses on the TC1 and assignment 1 which is the student's own project proposal.

The project tutors sub-divided TC1 further into 3 parts: (1) choosing a sensible topic, (2) understanding structures and time commitments, and (3) meeting the engineering requirements. Number 3 is particularly important as the project requires students to demonstrate solving problems in developed techniques using well-proven analytical techniques and apply their engineering knowledge to deliver a project using established technologies and methods (The Open University, n.d.). We then augmented these barriers, or threshold concepts, with student performance data from the module focussing mainly on their assessment and their predicted success which was modelled before the students started (Calvert, 2014) for the cohort of students in 2023.

Evidence for threshold concepts within projects

Previous research into doctoral education identified threshold concepts that occur during the development, implementation, and dissemination stages. Whilst the capstone project clearly differs from doctoral study, there are similarities in that students complete a project individually with the support of a supervisor, the project involves the collation and analysis of information/data,

and students have prolonged in-depth engagement with the project (Todd et al, 2004). As such a number of threshold concepts experienced by doctoral students are also experienced by capstone project students. During the project development stage this includes threshold concepts around selecting an appropriate project proposal (see TC1, below), conducting a literature review (TC2), applying theory, and designing methodology. Historic data for T452 demonstrates highest withdrawal rates during the project development stage of the capstone module, whilst completing a successful literature review also proves troublesome to many students. During the project implementation stage, project students may experience threshold concepts around analysing data, and during the dissemination stage students may encounter challenges around creating knowledge from their findings or writing a report. Tutors on the module reported the 3 largest stumbling blocks as: choosing a project (TC1 – development of the project proposal), completing a successful literature review and then carrying out the work (TC2 – implementation of the project), and writing a great final report (TC3 – dissemination of the work). These three TCs are displayed in Figure 1 as a function of time as the project runs from late January until mid-September. Assignment due dates are shown in the dark circles and the final project is shown as a milestone (dark diamond). They overlap very well with the 3 key assignments in the project. All assignments in the project are required to be submitted to gain an overall pass, and each one must gain at least 30% overall.

There is evidence for students struggling on the module at the specified points noted by their tutors. Approximately 10% of the cohort withdraw before the project proposal is due, with another 4-5% withdrawing shortly after they have feedback from their project proposal (see Figure 1, January to March).

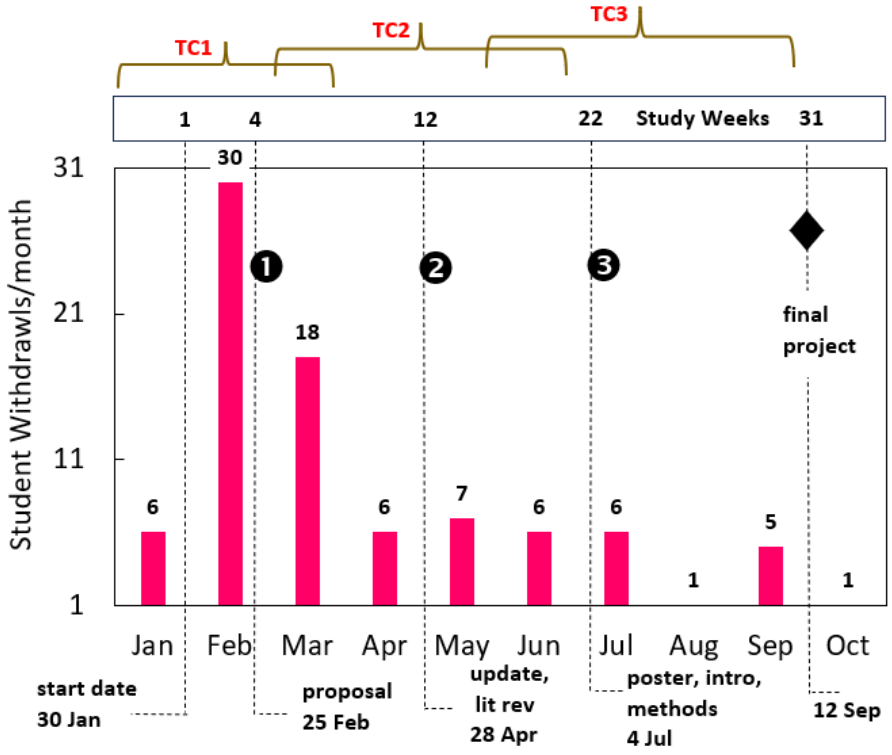

Figure 1: The number of students who withdrew each month is shown in the bars. Assignment dates locations are shown in the filled circles, with the final project shown as a filled diamond. Threshold concepts (TC1 to TC3) are also shown with their approximate time scales.

Many students revise their project proposals after they get formal and detailed feedback from their tutors. Students also receive feedback from the internal examiner, a module team academic, and this feedback is parsed into 4 major categories: Acceptable, Acceptable with Minor modifications, Acceptable with Major modifications, and does not meet with T452 requirements. Many students get discouraged by getting critical feedback which indicates they have a good project but that it needs more work, or more revision to meet the module outcomes. However, to balance this potentially demotivating feedback all internal examiner feedback reports tend to give detailed suggestions and guidance for improvements allowing student to adapt and progress their work into a more favourable position. A more in depth of analysis of the examiner feedback is ongoing but in general the distribution of students for the 4 categories listed above, respectively, is: 22.8% acceptable, 42.1% minor, 27.4% major, and 7.6% unacceptable (major re-write/ re-think of entire project scope as it does not meet the module requirements).

Given that 35% of all students in this sub-set needed either major or Unacceptable (complete re-think) - this is very good evidence for TC1, but also lends evidence that TC1 is continuum towards further barriers, and thus ultimately completing the module successfully. Even if there is probably a degree of error dependent on the academic judgement of the internal examiner – when 2 examiners wouldn't agree on a single category for a submission – these categories attest to the difficulty of scoping the project correctly to the meet the module learning outcomes.

The process of continually refining the project can be difficult for students especially if they are not used to working in this mode, where activities and priorities can change due to changing project requirements. Even students who are previously successful at distance learning have issues with projects and independent learning (Hush, 2015). These students sometimes perceive the independent learning process as being too unrefined or without sufficient direction to keep them moving forward towards the end goal of project submission (See Figure 1, September). It is observed that students continue to drop out each month and the exact reason for them stepping off the module is not always fully known. More work is required in this area of withdrawals for project students.

Students also note that it can be difficult to link their project scope to the concepts within the literature that they have discovered. This disconnect between their applied real-world work and the theoretical is sometimes also considered a serious threshold in their learning journey. This is captured at TC2 within Figure 1.

Do late students have poorer scores and higher predicted risk values?

Yes, in general there is evidence showing students with extension have slightly lower scores and this is summarised in Table 1, below. Students with higher risk values (i.e. likely to not pass the module, 0-60%,) have much higher levels of being late. This complex picture of risk [high, medium and low] is shown in Figure 2 for all students from the start date. The majority of students are considered low risk (LR) or medium risk (MR) based on their predicted probability of completing the project.

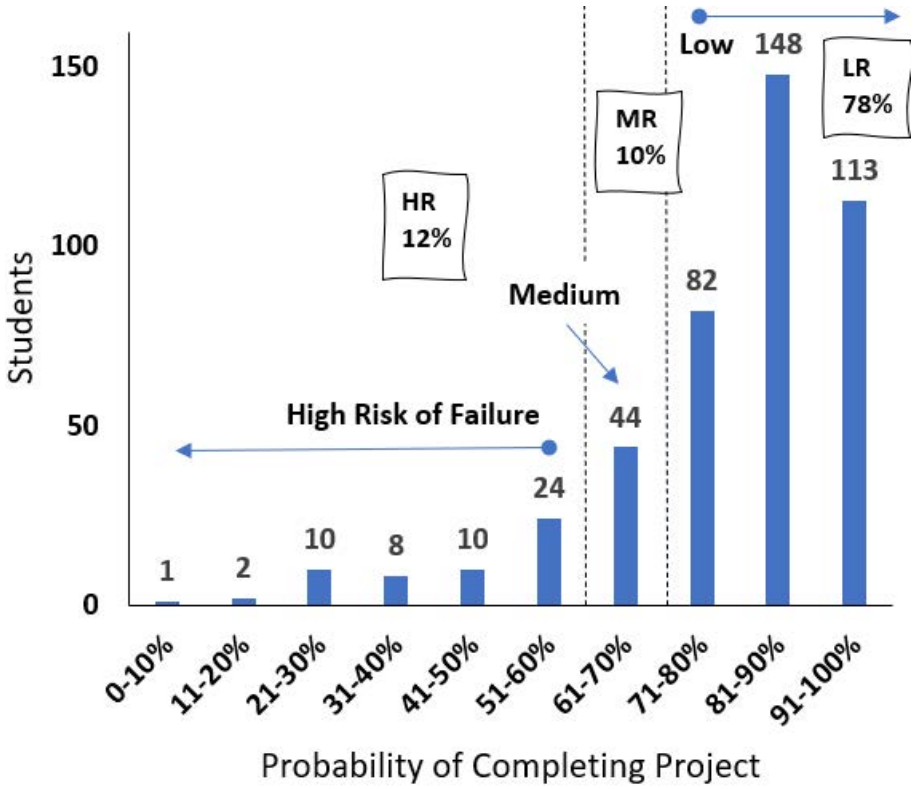

Figure 2: The predicted probability of completing the final year project for each student as shown in decile bands. Low risk students tend to succeed and high risk students tend to not complete. Total students 442 at start of module in 2023.

Assignment 1 descriptive statistics are displayed in Table 1 lending support to the theory that TC1 (completing the project proposal) does indeed exist. Lower overall average scores and higher risks of not completing the module are observed in almost all cases. In general student outcomes were as follows:

- The majority (67%) of students submitted on time and this means about 1/3 of students were late or had valid extensions during the project proposal (Threshold Concept 1).
- Of the 95 students in the Higher Risk category (0-60% probability of not passing module) just over half needed an extension. This contrasts with 311 students who were 'lower risk' - only 28% had an extension.
- For 2023 cohort, late students in general had lower overall assignment scores, and although this was not consistent for all risk categories, in general on time students tended to gain 2-8 more marks overall. At the lowest probability values (high risk of not succeeding on the module) late students had marks significantly lower than their 'on time' counterparts. All late students compared to all on time had a difference of 9 marks – 64% and 73%.

APM Competence	High and Medium Risk of Failure	Low Risk of Failure
Late	59% (47 students)	70% (86 students)
On Time	69% (48 students)	74% (225 students)

Table 1. Matrix displaying individuals in each category (in parenthesis) and overall average assignment marks (percentage) as a function of being late and modelled risk of not passing the module. Total students completing Assignment 1 was 406 at the time of the due date.

If one accepts that the model predictions are correct for low risk students, then approximately 311 students should complete the project and pass based on Table 1. The aggregate predicted pass rate is approximately 76% and our actual value was 78%. The predicted rate changes over time as students may drop out in the future even though they have completed much of the module work, and this can be observed by noting the low risk students in Figure 2 are as high as 343. The continual decrease of student numbers during the presentation confirms that overall numbers decline. As this work is focussed on those students who are struggling with the threshold concepts in the module, we are mainly interested in those 95 students with the predicted higher and medium risks.

What are the key variables associated with passing the project?

The modelling predictions indicated that assignment scores and their overall (module) results on previous modules along with early VLE Usage on the project were key indicators of success for the engineering project.

The analysis also leads us to ask which variables within a predictive model highlights as key items when trying to determine student pass rates. In this case the data is amalgamated over a series of presentations (or years or cohorts) in order to ensure the data set is large enough to yield significant trends. Clearly each cohort is quite different in their demographics and background study patterns, and the annual average pass rate for the module was 67.2% to 77.1%. This variation of outcomes highlights the issues which are evident each year showing that typical variation observed for large cohorts of students.

The key variables observed, which correlated with higher predicted pass rates, were: (1) students that have received a score of 64% or above on their last module, have an average predicted pass rate of 83% (2) students with a previous pass rate across all modules taken. [If they have passed 78.% or more of their modules, then they will likely fall into a group with a predicted pass rate of 86%] and (3) engagement on the VLE (virtual learning environment) for at least 42% of the days between module start and within the first two weeks of study, then their likelihood of passing could grow to 92%. Conversely, students who are likely to not complete are those who have low levels of interaction with their coursework online, and have either failed a previous module, or had poor scores on their previous completed modules. These are the group of students with higher and medium predictions. Tutors that support project students need to be aware and able to intervene if they observe students who are: struggling with scoping their proposal, likely to be late, have a poor outcome on their examiners report, and failing to work in the VLE.

Conclusions and Discussion

By applying threshold concepts (TCs)(Meyer and Land, 2003, 2006) to the final year engineering project one can find multiple pieces of evidence which seem to strongly support TCs throughout the module. Tutors readily identified and shared their knowledge of where and why students struggle to progress within the module materials. These three major pinch points were mapped against assessment by using the assignments and the final project report to signify specific TCs over time that the tutors had nominated as the most important barriers to progression.

Lateness, low assignment 1 scores and modelled probability of passing the module all supported the general theme that project modules are difficult for students partly due to threshold concepts which they have not encountered before. Probability modelling was useful for mapping the key variables which predict

student success. This model predicts that student success is driven by three key variables: success on previous module, success on all their previous modules, and early engagement within the module learning environment.

Suggested areas for further discussion or work include a deeper inspection of the sub-groups of students on this project module to find out their reasons for withdrawal and link them to TCs. The module team would also like to consider how many students attempt to do the module more than once as a 'false start' to the module can also be a significant marker for not completing the module in the next year. More work on study intensity, student outcomes and student motivation are required for a better understanding of retention on the module.

Consideration of using the same techniques explored here within other project modules within STEM such as final year computing, and the capstone science module. Within all these projects there are sub-themes present as students can choose their topic of choice which begs the question – do electronics students and mechanical engineering students experience the same barriers? Moreover, knowing that there may be TCs within the module, in what ways can we share this information with students to make them more fully informed for their forthcoming study? Verifying that students also feel these TCs exist merits more work (Barradell, 2013); if we can find ways of reducing student stress with respect to these learning hurdles they should be utilised in all project modules when appropriate.

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