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# Engineering Solutions – an innovative pedagogy

## Support material

Problem-based learning  
resources



## The Engineering Solutions project

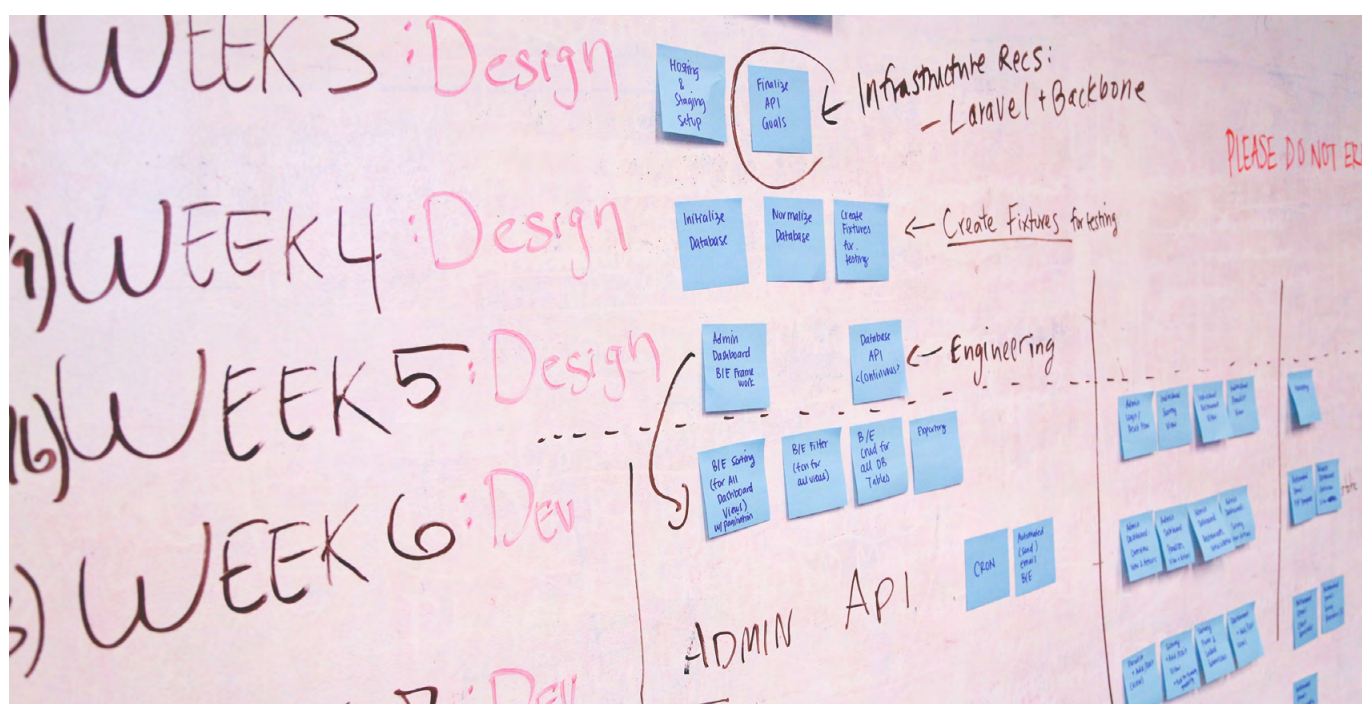
The Engineering Solutions (ES) project consists of a teaching and learning approach (Problem-Based Learning) supported by a set of student resources and teacher guidance. ES draws heavily on research evidence showing that interest in Science Technology Engineering Mathematics (STEM) education is increased by emphasising a 'people-centred' rather than a 'kit-centred' approach (Bevins and Price, 2016) and on the RAEng report *Learning to be an engineer* (RAEng, 2018). This document describes how the theoretical and research-based insights are operationalised in the resources.

## Problem-Based Learning

Problem-Based Learning (PBL) is an approach to teaching and learning that explicitly values student autonomy, student-led investigative activities, collaboration, communication and reflection all typically contextualised in real-world practices. Students are given opportunities to problem-solve in a collaborative setting, create mental models for learning, and develop self-directed learning habits through practice and reflection (Hmelo-Silver, 2004; Norman and Schmidt, 1992). Heavily framed by constructivist principles, PBL offers a pedagogical approach that encourages active and group learning framed by a belief that effective learning is stimulated when students construct knowledge for themselves and co-construct with others (Glaser and Bassok, 1989). PBL is iterative in nature involving teachers/lecturers acting as facilitators to guide and advise students through the learning process, while encouraging autonomy and responsibility within their learning.

Typically, PBL begins with a problem to be solved in a real-world context. Students then draw on their existing knowledge as individuals and collectively to analyse the problem. They may identify supporting resources that will aid their understanding of the problem and stimulate collaborative discussion. Collaborative group discussion encourages reflection on learning through shared views and perceptions. Reflection is an important component of PBL as it can enable students to develop deeper understandings of themselves as learners, as well as offer a collaborative agreement regarding the problem and potential ways forward (Savin-Baden, 2000).

Despite many existing studies which praise the effectiveness of PBL in terms of positive impact on student achievement, few studies have investigated the process of PBL in an attempt to interpret each component accurately. However, one such study (Gijsselaers and Schmidt, 1990) found that the quality of a problem significantly influences collaboration between student groups, which then stimulates the quality and time spent on individual study. Van Den Hurk, Dolmans, Wolfhagen, and Van Der Vleuten (2001) studied three phases—problem analysis, individual study and reporting. The authors found that the range and depth of emerging issues during analysis of the problem influenced the quality of the students' research leading to deeper understandings and explanations which in turn, positively impacted achievement. These studies highlight the typical phases that characterise PBL, provide evidence of the effectiveness of each phase as a contribution to increased motivation, understanding and ability to work in collaborative groups.



## A holistic view

Dabbagh & Dass (2013) suggest that a problem can occur if PBL is treated as an 'add on' to more instructional styles of teaching where students are offered a particular problem or project to provide experience of applying their learning after direct instruction. The authors suggest that in this scenario it is often the case that the focus is on the problem at the cost of meaning-making, collaboration and reflection. Whereas the most effective approach incorporates each component.

Engineering Solutions avoids de-emphasising or skipping the meaning-making, collaboration and reflection components of the cycle by giving each equal prominence. In other implementations of PBL, so much time can be spent on a first attempt toward a solution that there is little time left for the iterative cycling that PBL calls for (Dolmans, De Grave, Wolfhagen, & Van Der Vleuten, 2005; Hong & Choi, 2011). So we encourage realistic problems that are soluble within the timeframe rather than trying to cover every aspect of a problem (Hmelo-Silver & Barrows, 2008).

## Problem selection

Selection of an appropriate problem as a context for learning is crucial in PBL. The problem should relate to real-world contexts to encourage learner relatedness. Learners will select existing resources and literature to support their analysis based on how well they codify the problem. This will also impact the quality of discussion in collaborative groups. If the problem remains ill-defined throughout the process, it is likely that learners will be less motivated to search for answers for the problems discussed.

Identifying a problem that connects learners to the real world is essential to encourage motivation and relatedness (Deci and Ryan, 2002). This then positively impacts engagement through individual study and collaborative groups, that in turn, leads to a deeper understanding of the problem and a solution design based on rigorous analysis and planning.

## Motivation

Research over many years shows. In simple terms this means greater learner engagement if the resources lead with stories of real-world contexts. By placing the learning objectives in real-world contexts learners are more likely to persevere with the work while feeling connected to the content. Research is also clear that offering problems where students create and work with multiple viable solutions to review, choose and optimise amongst these, is more motivating than requiring a single approved solution.

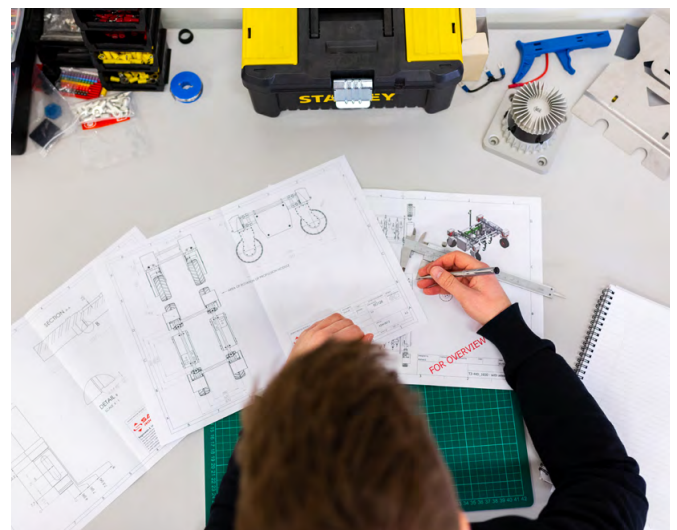
Deci and Ryan's (2000) Self-determination theory (SDT) identifies the importance of intrinsic motivation on cognitive and social development through active engagement in learning. Learners practice self-determination as they proactively respond to environmental challenges within social groups (Deci & Vansteenkiste, 2004). However, Deci and Ryan (2002) also note that not all tasks will satisfy a learners' abilities and needs. To effectively develop students' learning potential and enhance intrinsic motivation, they identify three essential psychological needs:

- autonomy
- competence
- relatedness.

Autonomy exists when students take responsibility for their own learning. Competence is realised when students are successful at tasks that are challenging to their existing ability. Finally, students experience relatedness when they experience a sense of belonging to a particular community (e.g. engineers) or see what they are doing as in sympathy with their personal values (e.g. students who are concerned about reducing their carbon footprint are more likely to engage in work that supports this) or people whose opinions and approval they value (e.g. peers, parents).

## Collaboration and individual study

One of the advantages of learning in small groups, is that students can share information, clarify understanding, relate new concepts to existing ideas and learn to debate and defend their standpoint. The extent to which this collaboration happens will depend on the way students prepare themselves during individual study based on the problem presented. Learners are required to summarise existing literature, make notes, and recognise how they explain new concepts to their peers and others.



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Good individual study using summaries, note taking, reflection on what they have learned, learners reporting in groups and to facilitators will lead to deeper conceptual understanding (Gabbert et al. 1986). New relations between concepts are made, establishing a framework of deep and rich connections in their knowledge base (Van Den Hurk, Dolmans, Wolfhagen, and Van Der Vleuten, 2001).

## Scaffolding

Facilitators have a clear role in helping students through ‘scaffolding’ (Kim, Belland, and Axelrod, 2019). The concept of scaffolding can be defined as support from experts or more knowledgeable peers that enable learners to progress through structured tasks and guidance (Wood, Bruner, & Ross, 1976).

Moreover, in other situations, the facilitator may fail to provide students with the scaffolding they need along the way to focus their activity and to express themselves in rigorous ways. When the integrity of the PBL approach is compromised (e.g., the number of cases learners address is small, the iterative cycling is foreshortened, or reflection or scaffolding are deemphasized), the approach cannot be expected to produce the powerful results of a full implementation (Hung, 2011). Therefore, the Engineering Solutions approach emphasises scaffolding and provides resources to successfully implement effective scaffolding.

Kim, Belland, and Axelrod (2019) offer a range of scaffolding types for facilitators to consider:

- Conceptual scaffolding
- Metacognitive scaffolding
- Strategic scaffolding
- Motivational scaffolding

Conceptual scaffolding helps learners problematise tasks (Reiser, 2004) by providing context for the given task or problem as well as information regarding content. Concept mapping and other visualisation strategies are often used in this form of scaffolding. The key aim is to help students feel

that the given problem is worthwhile attempting by offering a suitable context and reason why the problem is important to their life experiences.

Metacognitive scaffolding requires students to reflect on their learning and encourages them to consider potential problem solutions. PBL necessitates students use of prior learning in order to develop their learning plan and approach.

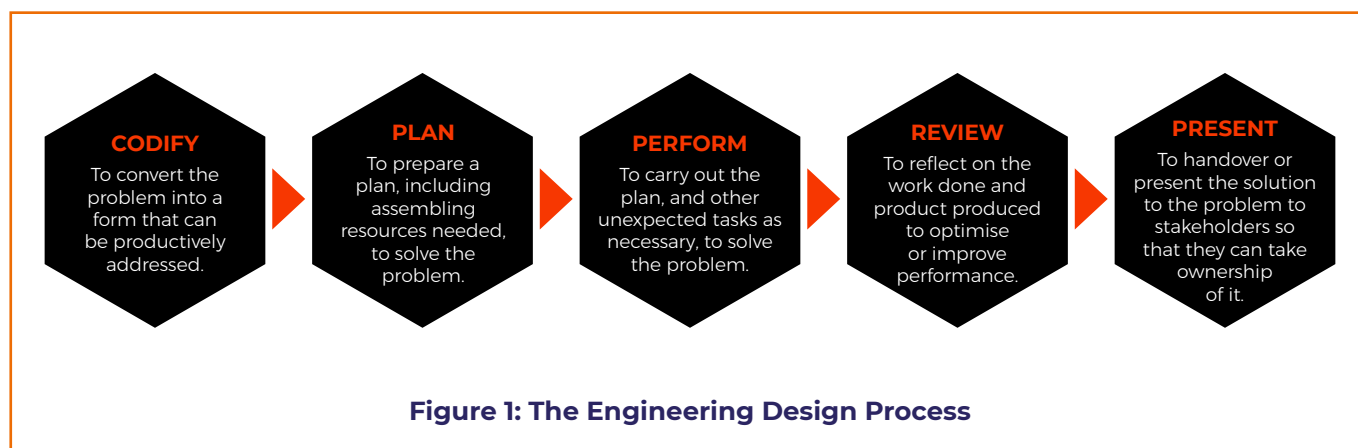
Strategic scaffolding focuses on providing guidance on generic problem-solving activities and strategies (e.g. the engineering design cycle). This may be in the form of teaching and learning resources and encouraging research. The key here is to help learners identify the ‘best evidence’ and the most effective ways to gather and deploy this to support their proposed solution.

Motivational scaffolding supports learners’ interest, confidence, and collaboration (Tuckman & Schouwenburg, 2004). It is likely that as learners accomplish their tasks, gaining confidence from conceptual, metacognitive, and strategic scaffolding, their motivation will improve. However, motivational scaffolding can directly improve students’ ability to persist in their learning and develop greater resilience when faced with challenges. These forms of scaffolding all support Deci and Ryan’s (2002) concept of the importance of developing learner autonomy, competence and relatedness.

There is a wide range of extant literature which provides evidence of the superior performance of students’ learning in PBL conditions as opposed to direct instruction (Yew, and Goh, 2016). The Engineering Solutions resources harness a PBL approach by providing supporting materials with teacher guidance for effective facilitation of the learning process.

## From theory to practice

In an attempt to operationalise these insights, ES uses an Engineering Design Process (EDP) (see **Figure 1**). While we recognise that any model can be an oversimplification and other versions



of the EDP are available the model here provides a useful way to organise the stages that support PBL and link it to the demands of the new T-Level qualifications in Engineering.

## Supporting PBL in ES

The resources are organised into 5 distinct projects:

- **Building a cliff railway** looking at design and operation of a cliff railway including calculations of the power needed to move the cars.
- **Electric vehicles: charging on?** which looks at developing and maintaining a charging station for electric vehicles.
- **Growing environments** which looks at control environmental conditions to maximise food production in a modern urban 'factory farm'.
- **Keeping pre-term babies safe** which looks at control systems for incubators.
- **Engineering opportunities** which is an open project allowing students to develop a project to match their own interests and circumstances

The projects share a common approach and illustrate the Engineering Design Process as shown

in **Figure 1**. The CODIFY and PRESENT components are focused on clients and their circumstances while the PLAN, PERFORM and REVIEW processes tend to be internal to the engineering team. This process is often shown as a cycle (the output from one cycle providing an input to stimulate another) and, while the project resources are based around a global arc from CODIFY to PRESENT, teaching and learning will inevitably involve some smaller repeated cycles, or cycles with some components omitted for convenience, throughout the 30-hour project.

Teachers notes describe open-ended projects that support this model. Exemplar tasks are mentioned to support students who might be finding it difficult to formulate a way forward but these are only examples of what might be possible rather than mandatory requirements. Students should be encouraged to develop their own work plans, within the limits imposed by the relevant specifications and college timetables, to prepare them better for the world of work. Other resources are provided to support students with particular tasks and we see these as more than a collection of technical content or skills transferred to learners through direct instruction.



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1.  
**CODIFY**

2.  
**PLAN**

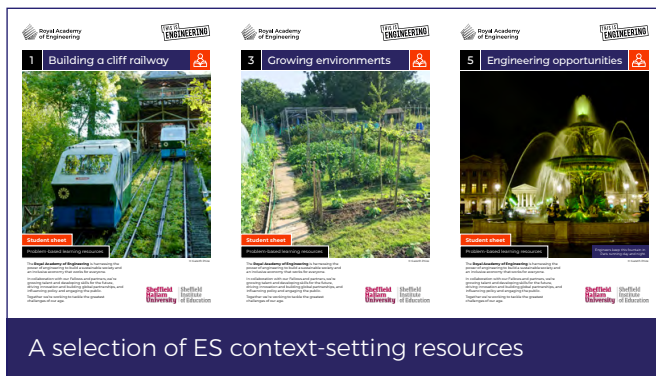
3.  
**PERFORM**

4.  
**REVIEW**

5.  
**PRESENT**

## CODIFY

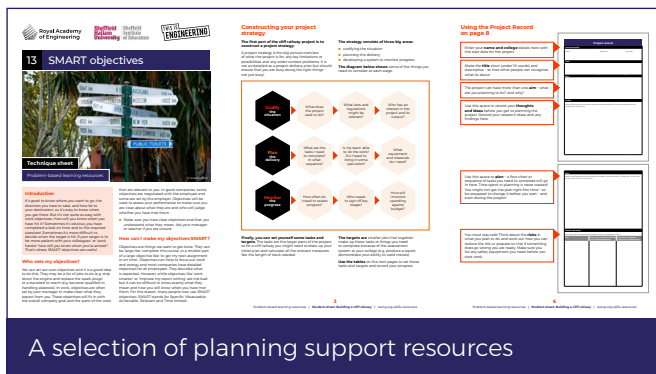
The CODIFY stage requires students to explore a context (potentially gathering more information from external sources) and form a view about a problem that is both solvable and worth solving in the time they have available. This emphasises their control over the process and maximises intrinsic motivation.



A selection of ES context-setting resources

## PLAN

The planning stage requires students to create a detailed and realistic plan of how they will deal with the problem they have identified. To support the process a number of resources are available including planning sheets to complete and more generic advice sheets on particular planning-relevant skills (e.g. Setting SMART objectives, Prioritising Tasks). ES seeks to avoid over-prescriptive advice so as not to undermine student motivation.



A selection of planning support resources

## PERFORM

Engineering is a practical discipline and the PERFORM stage in the process will almost certainly

involve time in a workshop or production facility of some sort. The T-Level qualifications certainly insist on a significant work placement and educators are responsible for preparing them for this time in the world of work. To support this, ES provides a series of support sheets that cover aspects of life in the workplace (e.g. Rights and responsibilities, Teamwork).

## REVIEW

Reflection is a critical component of successful PBL. This involves facilitators helping learners make explicit their reasoning, the knowledge they are drawing from, the connections they are making, and supply justifications for their decisions. The more effort a learner puts into identifying what can be learned, the better they will be able to categorise experiences and apply them. This means that reflection after problem-solving should aim to extract lessons learned from the problem-solving experience and anticipate contexts when those lessons could be useful. Facilitators play a crucial role in helping learners maximize the value of this type of reflection (Tawfik & Kolodner, 2016).

Reflecting on learning from previous experience is essential to nuancing learners' understanding of a problem. Consequently, it is important that facilitators help learners identify the previous experiences they have had that might be useful in solving the new problem. If learners explicitly learn from and apply their old experiences, they will be able to recognise distinctions and patterns that will help (Jonassen, 2011a).

ES projects require formal and informal reflection during and after the activity. Time is made available in the project plan and support offered in the teachers notes and student materials.

## PRESENT

Presenting work (including data, explanations and claims) in a specific format and for an identified audience can help students organise their understanding, check any misconceptions and apply their knowledge in novel situations or to unexpected purposes. There is a conceptual benefit from presentation activities that complements the obvious skills benefit. ES encourages presentation of material in all projects and offer support materials to structure this activity.

## Engineering Solutions support for PBL

To support the PBL approach, a set of technique sheets have also been developed. Each of these is structured around a series of questions that focus on key issues for each technique to help to

‘unblock’ students who are stuck or who need a reminder. They are not intended as the final word on a technique and always suggest ways that students could develop their understanding.

**Box 1** provides a list of these resources. Teachers can use them as required – they are not a list of techniques that must be covered by students.

### Box 1: Technique sheets

**1: Writing user instructions.** Preparing user documentation for a variety of devices (e.g. EV, incubator, connectors for struts in a temporary building) that can be used by people who have limited technical and reading abilities and may be working in non-native languages.

**2: Risk analysis.** Conducting a risk analysis for a process or project and identify key safety practices and equipment that would be necessary (legally) and advisable (good practice).

**3: Environmental assessments.** Considering the environmental impacts of a project (e.g. building a new gigafactory to make batteries) or change (e.g. a switch to EV cars) in the immediate and medium-term and for the local area and more widely.

**4: Working with triangles.** Calculating unknown angles and side lengths in triangles for assessing engineering measurements.

**5: Working with shape and space.** Calculating volume, height, angles of corners, articulations of a 3D shape (e.g. an incubator, temporary building, storage containers) based on measured or published data.

**6: Useful formulae.** Calculating safe working parameters for structural components (e.g. incubator trolley, temporary building roof or struts) based on measurements of properties of materials and published data.

**7: Converting between units.** Converting between different measuring units as appropriate (e.g. Celsius to Fahrenheit or Kelvin, metres to inches, metres to millimetres or kilometres).

**8: Calculating power and energy.** Calculating the power usage for a device or installation based on experimental measures and published data to plan a suitable power supply system.

**9: Costing a project.** Estimating the costs of manufacture for a device or structure (single prototype and multiple copies) based on cost of individual components and manufacturing costs.

**10: Knowledge inventory.** Identifying the knowledge base appropriate to a project and the likely future needs.

**11: Feedback.** Providing respectful, honest and helpful service to a colleague, subordinate on a product or service.

**12: Self reflection.** Reflecting on performance – how self-reflection can help development.

**13: SMART objectives.** Reviewing the characteristics and use of objectives to drive development.

**14: The urgent-important matrix.** Identifying priorities and strategies for work.

**15: Rights and responsibilities.** Identifying key rights and responsibilities in the workplace and how they affect working life.

**16: Managing meetings.** Facilitating a meeting to explore possible solutions to a problem, generate a decision and a report with clear recommendations and their justification.

**17: Teamwork.** Developing strategies for successful team working – and suggesting behaviours which can undermine teamwork.

**18: What's worth doing?** Deciding which parts of a project or work package should be done first.

**19: Choosing a site for an engineering project.** Conducting a site survey for a construction project (e.g. cliff railway, EV charging station, temporary building) or installation (e.g. installing a computer server, refrigeration unit) taking measurements of key features to produce a detailed map with significant measures clearly marked.

**20: Making a pitch.** Preparing a pitch or proposal for a piece of engineering work (e.g. a cliff railway, production facility).

**21: Delivering a presentation.** Present a pitch (e.g. a cliff railway, production facility) to a body that will make the decision on basis of needs, costs, suitability, sustainability.

**22: Responding to a brief.** Developing a strategy to deliver on a brief or win a tender.

**23: Managing large projects.** Using timelines, GANTT charts and systems to organise and track project progress.

**24: Preparing reports.** Understanding the nature of reports (content and structure) and prioritising what should be included, or omitted, from key reports.

**25: The engineering design process.** Using the engineering design cycle to stimulate creative solutions to problems.

**26: Planning a project.** Creating a detailed plan for a project.

**27: Keeping a logbook.** Using a logbook to record key events in a project.

**28: Creative thinking.** Increasing your ability to think creatively.

**29: Constructing a project strategy.** Developing a high level plan to tackle a complex problem.