Transforming Your Teaching: An E-guide to Support Educators in Enhancing Student Learning Outcomes

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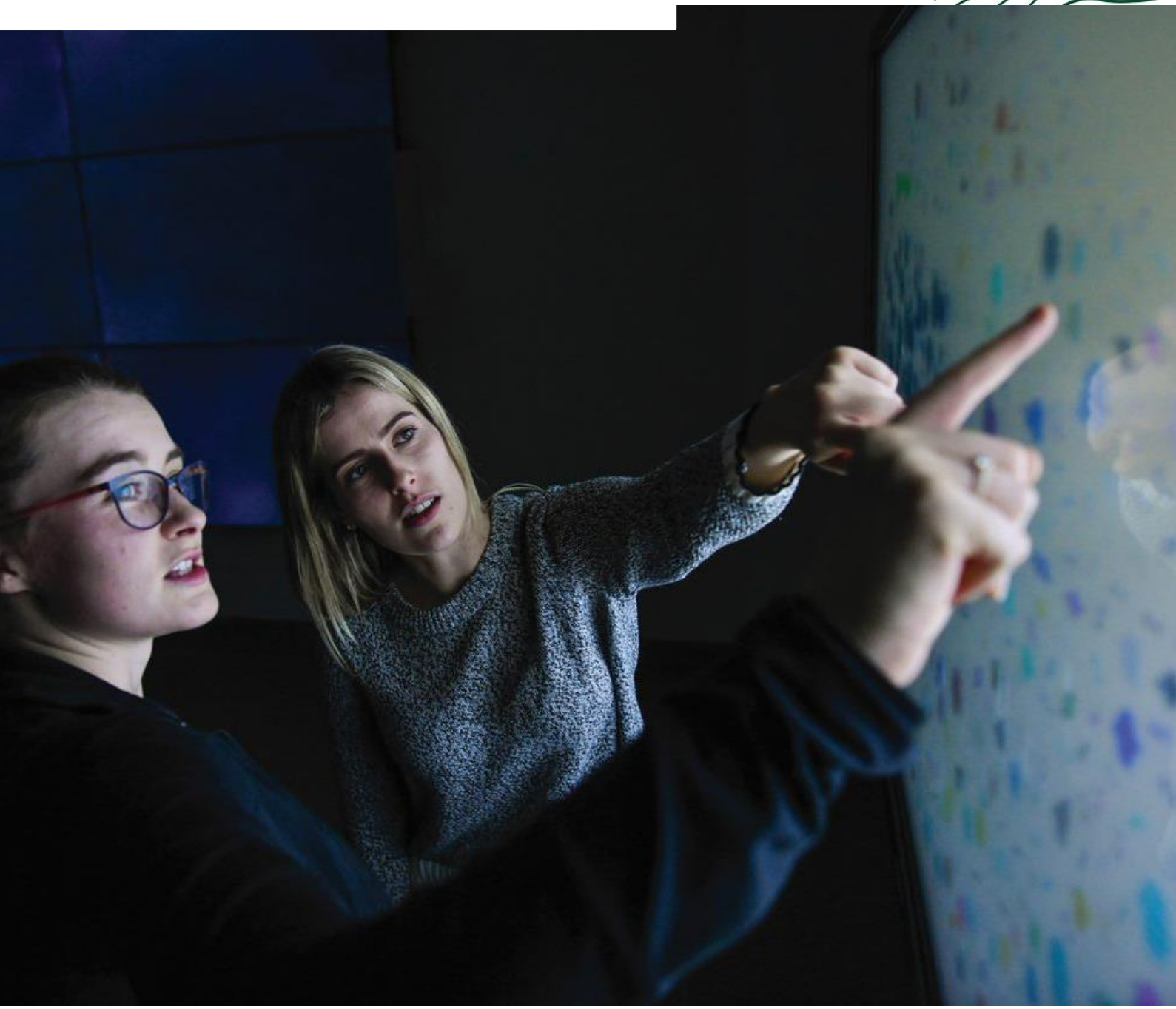
Enhancing Digital STEM



Transforming Your Teaching

A Guide to Support Educators in Enhancing Student Learning Outcomes

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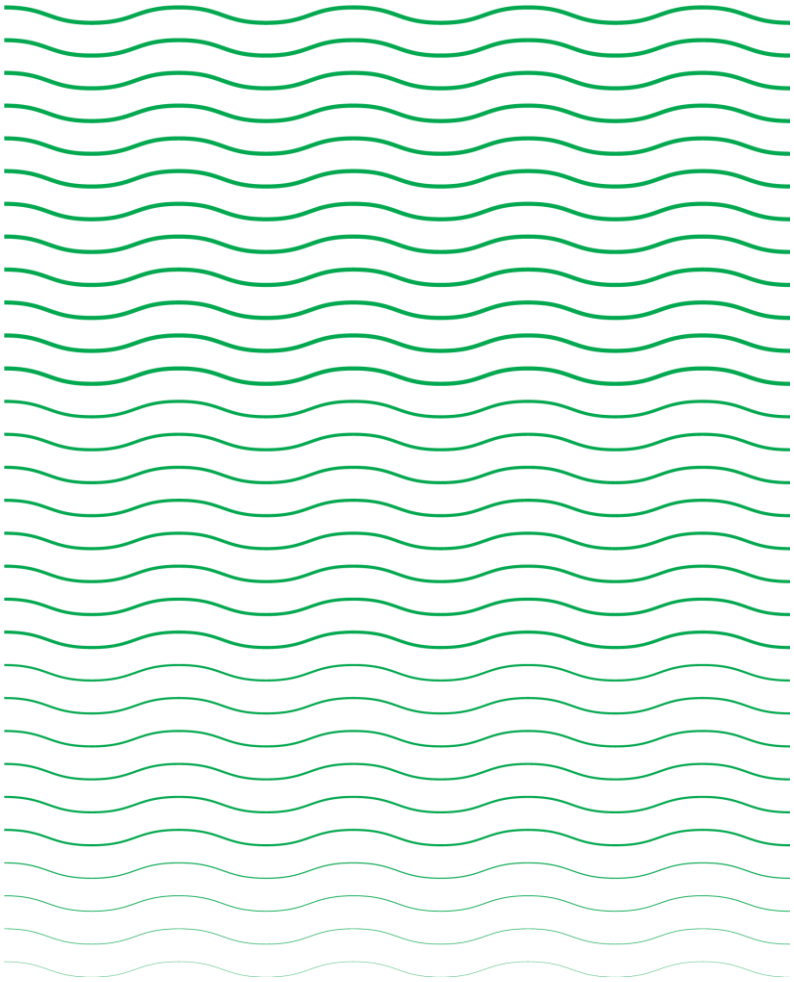


Chapter 1
Introduction

1 Introduction

The purpose of this guide is to provide a selection of strategies and factors that are directly relevant to STEM educators in a University setting. Selections of topics were based on strength of existing evidence and ease of implementation. This is not an exhaustive list and instead aims to provide you with a concise selection that can be integrated with your existing practices.

The roots of STEM education can be traced back to the second half of the 20th century when countries started to focus on improving science, mathematics, and technology instruction [1]. Since then, STEM education has become a key focus of educational reform efforts around the world, recognising the importance of preparing students for future careers in STEM-related fields. Looking towards the future, STEM education will continue to be a critical component of education, as governments continue to recognise the social and economic need for high quality STEM graduates.

According to EU Digital Education Action Plan (2021-2027)[2] the majority of stakeholders believe that how we teach and how our students learn has been permanently changed as a result of pandemic adaptations. The report outlines how a significant proportion of educators had never adopted blended learning strategies previously, but now intend to keep using the most impactful strategies after the pandemic restrictions passed. However, this in turn highlighted a lack of evidence-based guidance designed to support these educators.

This guide was developed with the support of funding from an EU-project called **Enhancing Digital STEM**. This project addresses the need to provide accessible evidence-based material to help educators make informed decisions within STEM education. Currently, educators practicing within digital STEM environments face an unreasonably high barrier of entry to evidence-based strategies which are frequently presented within research papers leaning heavily on social science methods. The typical STEM educator is formally educated in the natural sciences or engineering disciplines and as a result, has not had the opportunity to develop social science related expertise that is often required to engage with research paper-based reports of evidence-based practice.

The project was funded by the Erasmus+ Programme of the European Union with a start date in 2021 and an end in 2023. The participants of the project are the University of Limerick, Chalmers University of Technology and RWTH Aachen University.

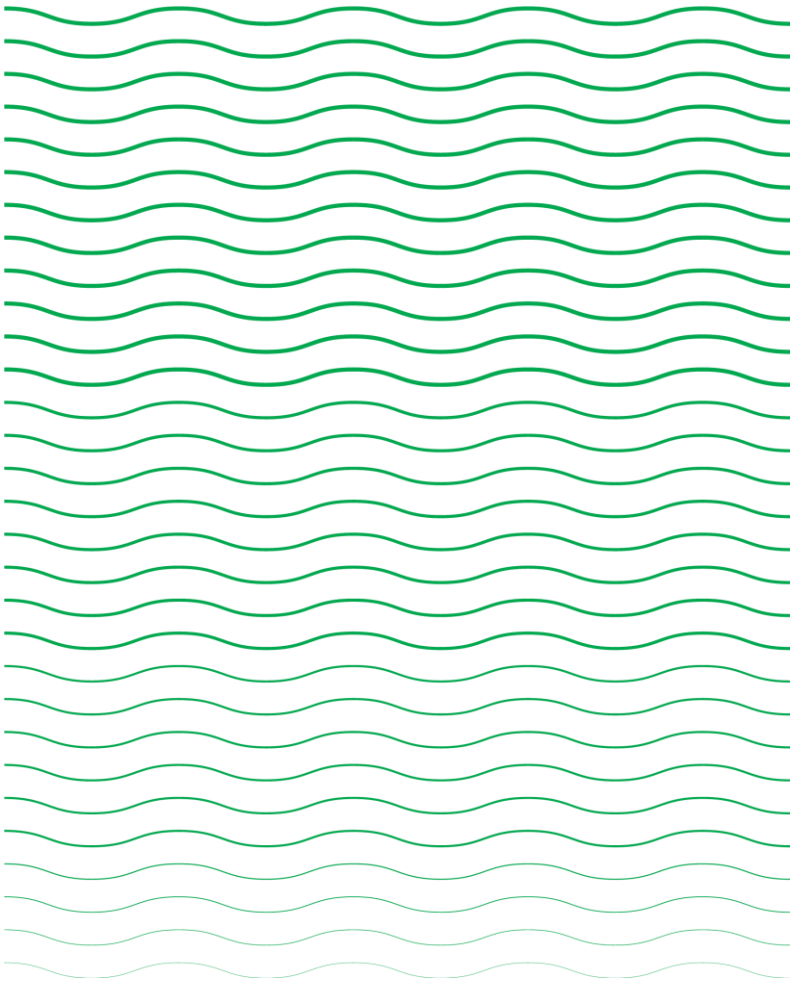
The goals for the project have been broken down to 3 objectives:

> *Objective 1*: Collate evidence-based practices that are compatible with STEM online learning environments and needs.
>
> *Objective 2*: Increase capability to critically engage with the evidence base through Professional Development Events.
>
> *Objective 3*: Create a Digital STEM Hub to support adopters of evidence-based practice. This guide is part of the results of the third objective and contains strategies and factors, which will help educators to enhance their ability to educate.

Associated supporting resources, professional development activities and project materials can be found at www.enhancingstem.com.

Links

- For further reading about the European Commission (EU) **Digital Education Action Plan** (2021- 2027):
  https://education.ec.europa.eu/focus-topics/digital-education/action-plan
- For further reading about the project **Enhancing Digital STEM**:
  https://erasmus-plus.ec.europa.eu/projects/search/details/2020-1-IE02-KA226-HE-000765



Chapter 2
User Instructions

User Instructions

The guide is divided into two major parts (*Figure 1*). First, it contains **strategies** for educators to implement in lectures, tutorials, etc. These strategies have been broken down to enhance readability: *Outline* (General information about the strategies), *Benefits and Challenges* (Contains Enhancers and Inhibitors, which are good to know for educators), *Implementation* (A guide for the educators on how to implement strategies in their context) and *Additional Links* (Links to supporting research). The Second part of the guide outlines **factors** which impact student learning. An awareness of these factors will allow educators to select the most appropriate strategies for their specific context and inform modifications to enhance impact. These are structured with the following headings: *Outline* (General information about the factors) and *Intervention* (Some guidelines and advice for minimizing the negative effects from the factors).

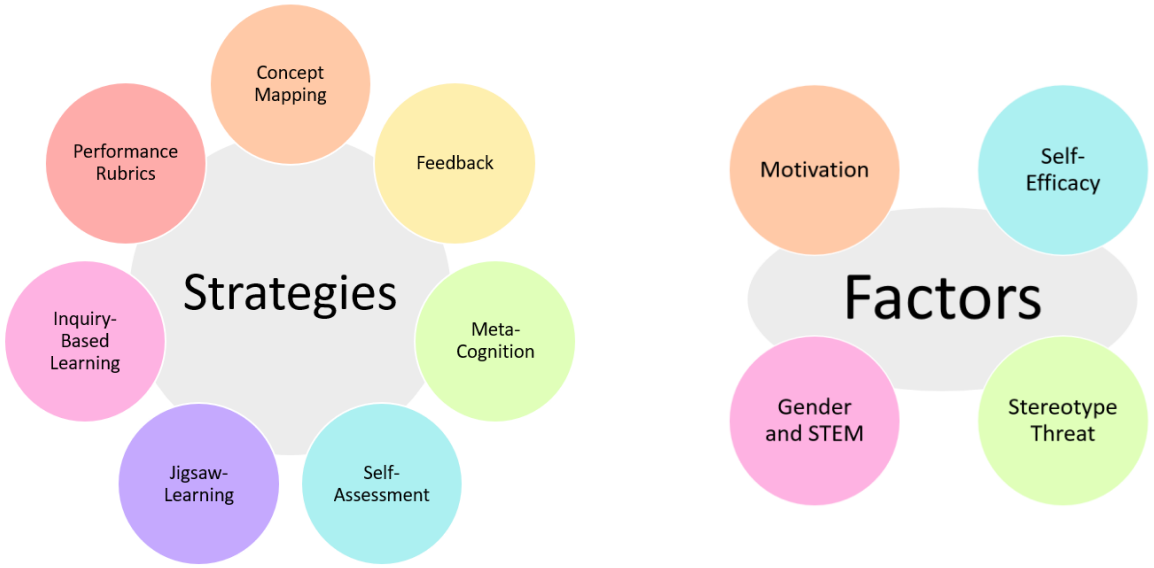


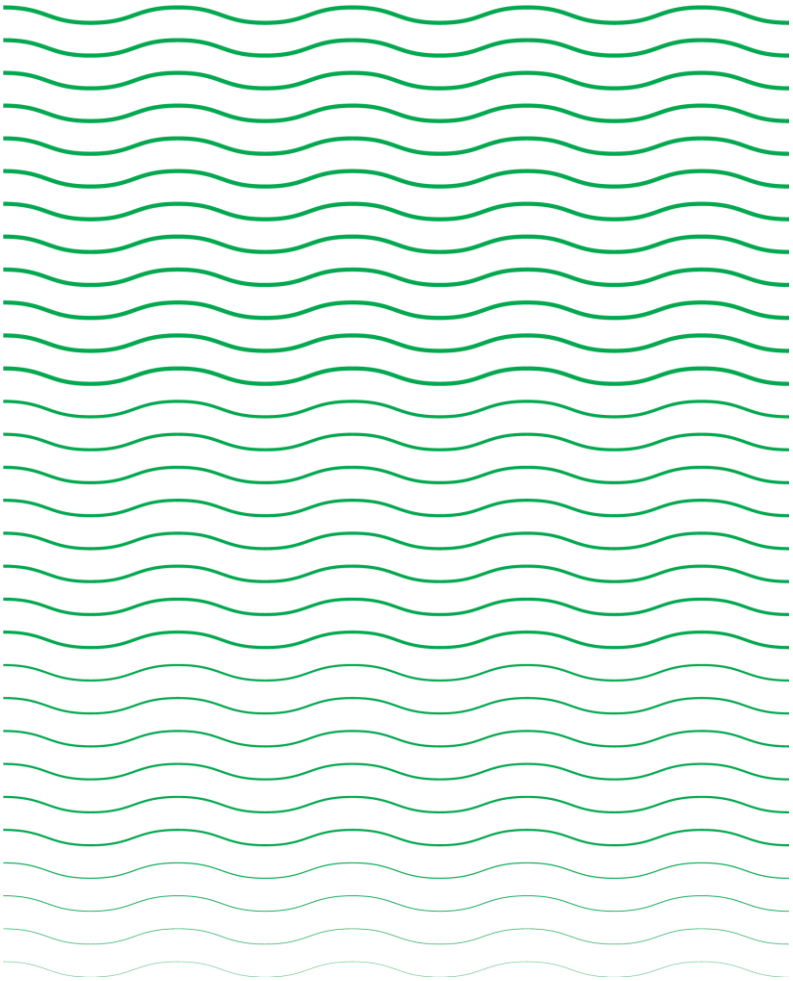
Figure 1: An illustration indicating the main content of this guide, outlining the most effective strategies and the main factors that influence student learning

The main goal of this guide is to support educators as they engage with evidence-based practice. It has been designed to minimise discipline specific jargon while maintaining links to high quality supporting research. The references to supporting studies, systematic reviews and meta-analyses are not required reading when implementing the outlined strategies, but should you wish to explore the evidence base in further detail we have prioritised supporting sources that represent best practice within educational research. In addition, if you chose to publish your practice in future you will find a large body of relevant research within the supporting references for each strategy.

Additional Links

There are many websites containing useful information to support evidence-based practice. The two listed below include numerous resources and guides should you require further information:

- Teaching + Learning Lab by Massachusetts Institute of Technology
  https://tll.mit.edu/
- Centre for Teaching and Learning by Queens University
  https://www.queensu.ca/ctl/



Chapter 3
Short Summary of Content

3 Short Summary of Content

The content in this guide is divided into strategies and factors (*Figure 1*). Some of the content will be more easily employed within your specific context and with your specific resources. Listed below is a short summary:

The Strategies:

Performance Rubrics: Rubrics are designed to enhance students' learning by providing clear criteria and supporting feedback. Ultimately this can help to develop a greater understanding of learning outcomes you wish the student to achieve. It can also support self and peer assessment.

Concept Mapping: Is a powerful tool for visualisation and understanding complex topics and tasks. The main idea of a concept map is to see relations between ideas and concepts. It can be implemented by both educators and students. It has a wide range of applications, e.g presentation and brainstorming.

Feedback: Is an essential component of the learning process. Effective feedback is crucial for student learning and growth, and educators must possess the skills to provide clear and constructive feedback to their students. Feedback can also be a powerful motivator. Positive feedback can help to reinforce good performance, while constructive feedback can help students identify their strengths and weaknesses, set goals for improvement, and ultimately enhance their learning outcomes.

Metacognition: This involves students "thinking about thinking", where they develop awareness about their own cognitive processes. This skill will help students improve their ability to learn and think effectively, and ultimately achieve greater success in their academic and professional pursuits.

Self-Assessment: Help your students improve their learning outcomes and achieve personal growth. Self-assessment has been shown to engage students in their learning and supports them in being able to judge the quality for their own work. This is an essential skill for higher educated people to possess in both professional and personal life.

Jigsaw-Learning: Is an effective strategy for promoting collaborative learning, active participation, and engagement in the classroom. By working together and sharing their knowledge, students can develop a deeper understanding of complex topics.

Inquiry-Based Learning: This requires students to actively pursue solutions and knowledge in response to carefully designed prompts. It emphasizes active learning over passive and has been linked with wider self-regulation development.

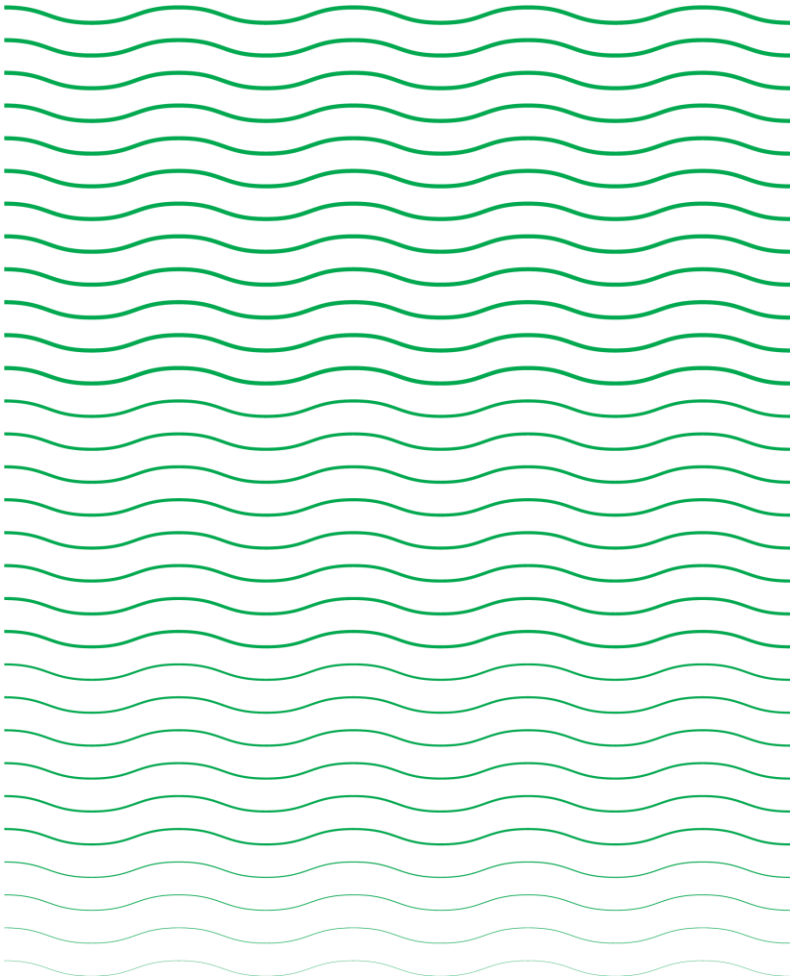
The Factors:

Motivation: Student motivation is significantly impacted by educators' actions and decisions. Here we consider how to utilise this factor within your teaching. Simple considerations like assessment designs, feedback systems and instructional strategies have all been shown to impact motivation development. Motivation has, in turn, been linked to student engagement, retention, resilience and academic performance.

Self-Efficacy: Students' beliefs around their capacity to achieve desirable outcomes is called self-efficacy. This belief has been linked to a wide range of desirable traits and behaviours in students. Students who report high self-efficacy are more likely to seek supports when struggling, more likely to graduate and more likely to recover from academic setbacks. Here we consider how this factor may impact your teaching, but also steps you can take to influence this factor.

Stereotype Threat: Harmful misconceptions about the suitability of group of people for a particular activity can have severe impacts on individuals' experiences and is known as stereotype threat. There has been a considerable amount of research that has identified the negative impact this factor has on the likelihood of women entering and persisting in STEM programs. Research has also highlighted links with the previously outlined self-efficacy and motivation theories. While difficult to impact, some relatively simple design considerations have demonstrated improvements.

Gender and STEM: Under-representation of women in STEM is resulting in severe economic and social impacts across the globe. A wealth of research has shown that this is impacted by a wide variety of factors and has been linked to the previously mentioned motivation, self-efficacy and stereotype threat factors. Research has identified some strategies and design considerations that can support female participation, increase retention and ultimately lead to a more inclusive learning environment.



Chapter 4
Strategies

4 Strategies

Strategies are discrete approaches that can be incorporated into existing lecture, tutorial or laboratory environments with relatively little modification to existing designs. These have been selected based on supporting evidence and suitability for STEM learning contexts. Each has been considered in terms of Cost (Required time, supporting systems, level of expertise) and Benefit (Strength of supporting effectiveness, likely impact) When outlining each strategy, a brief summary of relevant information and a guide for implementation is provided. These are not exhaustive academic reviews, rather they are the essentials that you will need to consider when making a change in how you facilitate student learning.

4.1 Performance Rubrics

When it comes to performance in education, there are two elements that come to mind: assessment and improvement. When combining both, the evaluation/assessment stage becomes more efficient when tools that continue to aid learning are used. A representative example of such a tool is the rubric.

Outline

Rubric is defined as a "document that articulates the expectations for an assignment by listing the criteria or what counts, and describing levels of quality from excellent to poor" [3]. A rubric can be used by educators with a dual purpose. *1:* to communicate the learning goals to students by setting out all learning requirements for the educational task at hand, *2:* to set specific grading points for each one of these learning requirements at any level between excellent and poor. In this way, from the initial stage of the educational activity, students are aware of their requirements while educators ensure consistency and fairness in grading. This dual purpose of rubrics is feasible due to their three distinct features [3], [4]:

1. Evaluation criteria: the parts/sections/aspects that the educator requires to be included by students into their assigned work.
2. Quality definitions: the expected level of answers, in detail, for each one of the evaluation criteria between excellent and poor.
3. Scoring strategy: the particular grading scale used.

Rubrics have multiple applications and can serve many different purposes in the educational process. They can be used as an educators' feedback tool for delivery enhancement, feedback to students to support their learning and as grading tools [3], [5]. As grading tools, rubrics that are well designed for this purpose, are valuable tools for reliable grading among multiple graders or the same grader in different points of time, given that relevant training has been received [3]. Furthermore, rubrics can be quite flexible in the level of detail they can hold. Depending on the purpose of their design, rubrics can be either specific or more general [4]. For examples see (*Figure 2*)

Score	Description
Excellent - 4	The report is engaging and interesting, holding the reader's attention throughout and demonstrates a thorough understanding of the topic.
Good - 3	The report is generally engaging and interesting, holding the reader's attention and demonstrates a good understanding of the topic.
Fair - 2	The report may be somewhat engaging, but may not hold the reader's attention throughout and demonstrates a limited understanding of the topic.
Poor - 1	The report is not engaging and does not hold the reader's attention and demonstrates little to no understanding of the topic.

(a) Holistic

Criteria	Excellent - 4	Good - 3	Fair - 2	Poor-1	Score
Communication	The essay clearly and effectively communicates its purpose and main ideas to the reader.	The essay generally communicates its purpose and main ideas to the reader.	The essay has some difficulty communicating its purpose and main ideas to the reader.	The essay does not effectively communicate its purpose and main ideas to the reader.	
Organisation	The essay is well-organised and easy to follow.	The essay is organised and mostly easy to follow.	The essay is somewhat disorganised and may be difficult to follow.	The essay is poorly organised and difficult to follow	
Language	The writer demonstrates a strong command of language.	The writer demonstrates a good command of language.	The writer demonstrates a limited command of language.	The writer demonstrates a poor command of language.	
Spelling	The essay is free of spelling and grammatical errors.	The essay has a few minor spelling and grammatical errors.	The essay has several spelling and grammatical errors.	The essay has numerous spelling and grammatical errors.	

(b) Analytic

Description	YES	NO
The report is well-written, with clear and concise language.		
The report is well-organized, with a logical structure and clear transitions between sections.		
The report is engaging and interesting, holding the reader's attention throughout.		
The report has a consistent formatting style (e.g., font, spacing, margins).		
The report includes a clear introduction, body, and conclusion.		
The report includes citations and a reference list for all sources used.		
The report is free from plagiarism and other academic integrity violations.		
The report meets all other requirements specified in the assignment instructions.		

(c) Checklist

Figure 2: Three of the most common performance rubrics used in STEM education

Overall, the use of rubrics has demonstrated numerous positive impacts across a wide range of international settings. Researchers have noted that the use of rubrics is associated with enhanced academic performance and increased student motivation [6]. This strategy has also been linked to Metacognition, which is a related factor that you can learn more about in the **Factors** section of this book.

Benefits and Challenges

The benefits are numerous. The rubric can not only can be used by educators as a grading aid, but also by students as a learning aid. By using the rubric to grade peers, or their own work, students develop a greater understanding of the key performance criteria for the current assignment. Consequently, the students are better equipped to produce a complete assignment, to improve the quality of their work, while, at the same time, they possess the criteria for self-evaluation of this work [3], [5], [7]. Also, there is no limit in the type of students' work that rubrics can be used. They are widely applicable and have been used in written, oral, video, audio format of students' work, formal and informal assessments, practical and theoretical work [3]. A more detailed list of the known enhancers and inhibitors of performance rubrics are presented below:

Table 1: Enhancers and Inhibitors (Performance Rubrics)

Enhancers	***Inhibitors***
• *Rubrics have multiple uses (learning and assessment aid, feedback tool) with positive results* [3]. • *Rubrics can be used with any type of students' work and can support peer/self-assessment* [3]. • *The use of rubrics is associated with enhanced academic performance and motivation* [3], [5]–[7]	• *Appropriate language, content and expectations for relevant audience are necessary* [3], [4]. • *Training is advisable* [3].

Implementation

Performance rubrics can have different types of structures depending on the purpose. The most common are **holistic:** (*Figure 2a*). The criteria are not broken down into specific components, graders/correctors judge the performance of students by an overall impression. Suitable for evaluation of creative works or tasks which has undefined solutions. **Analytic:** (*Figure 2b*) The criteria are broken down into specific components or categories. Each component is evaluated separately and has a score,

the overall grade will depend on the sums of the total scores. Suitable for more complicated and structured tasks, it provides more detailed feedback. **Checklist:** (*Figure 2c*) The criteria are specific and the graders/correctors decision is binary (pass/fail). Suitable for mathematical tasks or multiple-choice questions [8].

Before defining the criteria, the desired learning outcomes from the task should be established. The performance rubrics should be based in the learning outcomes. It will act as a guideline for educators in their grading/correcting, but also for students in their work. The next step is to identify what to assess according to the learning outcomes, and then decide a suitable structure for the performance rubrics.

Defining the criteria in a performance rubric typically requires listing and describing the required knowledge, skills, and abilities to complete the task. The number of criteria is normally between 3-8, similar criteria can be combined and be more specifically described in each level of performance. Listed below are a short summary of questions to reflect over, to help create the right criteria for the task [9].

- *What do you want students to learn from the task?*
- *How will students demonstrate what they have learned?*
- *What knowledge, skills, and behaviours are required for the task?*
- *What steps are required for the task?*
- *What are the characteristics of the final product?*

Depending on the structure of the task the levels of performance can differ. This paragraph is mainly for analytic and holistic structured performance rubrics, as checklist rubrics don't contain multiple levels of evaluation. The number of levels in an analytical structure should at least be 3, but often contains 5 levels [10]. The levels' labels should have names that clarify what the levels represent to the performance, e.g *Excellent, Pass, Fail*. This will motivate the students to aim for even better-quality work.

Next step is to decide and describe each level of performance (grading descriptors). This will help educators to be objective and consistent in the rating of students' work. It will also help students to get a clear picture of what is expected of them. The description should be more specific and about what it takes for students to reach that level. Listed below is a summary of the content of creating performance rubrics [11].

1. Consider the desired learning outcomes.
2. Identify what to assess.
3. Select an appropriate type of rubric.
4. Define criteria.
5. Identify the levels of performance.
6. Describe each level of performance (grading descriptors).

In general, it can be difficult to formulate criteria and suitable descriptions. The language of Bloom's Taxonomy from **Taxonomy of Educational Objectives** is a useful aid. It focuses on categorizing educational goals and is considered a seminal text [12]. In *table 2* are several suggested words listed correlated to educational goals. This may help educators to communicate the desired learning outcomes with students [13].

Table 2: The Language of Bloom's Taxonomy

Goals	***Suggested words***
Evaluation	*judge, evaluate, compare*
Synthesis	*design, organize, formulate*
Analysis	*analyse, test*

Application	*demonstrate, illustrate*
Comprehension	*describe, explain, discuss*
Knowledge	*define, list, name*

Additional Links

For further reading and understanding about *Performance Rubrics* it is referred to links below:

- Use of rubrics by MIT Teaching+ Learning Lab
  https://tll.mit.edu/teaching-resources/assess-learning/how-to-use-rubrics/
- Example of performance rubrics by University of Limerick
  https://staff.ul.ie/slatteryd/grading-rubrics
- Guide to Developing Rubrics for Assessments
  https://www.polyu.edu.hk/wgsqa/images/content/WGSQA_Rubrics-Manual-Full_Ver.1_20191101.pdf

4.2 Concept Mapping

Engineering education seeks to develop more than the direct skills that are required for a specific aspect of engineering. Engineers are required to think, calculate, plan, design and troubleshoot throughout a wide range of projects. As a profession, engineering includes demands for a particularly broad conceptual knowledge and skill base [14]. Being able to link complex forms of knowledge and skills together in pursuit of a goal is a capacity that can be developed. Concept Maps have demonstrated considerable value in supporting this type of student development.

Outline

Concept Maps were introduced by *J. D. Novak* in the 1980s and are still used extensively in science and engineering education, aimed mainly at students' successful understanding and deep learning. This process includes conscious upgrading of already established knowledge, by adding new knowledge [15]. Concept Maps succeed in this by placing concepts hierarchically while linking them together to show their relationships. This activity can help students to link their newly acquired knowledge with prior learning. Therefore, it is a teaching technique and a learning strategy that aims to help students to learn and orientate concepts within complex contexts [16], [17].

The Concept Map is a two-dimensional block diagram that determines the relationships among the basic concepts of an area of study. Due to its biaxial nature, it is the appropriate instrument for the presentation of the relations among concepts with the help of directional linking lines [18]. The concept map, usually a downward-branching hierarchical layout, consists of concepts with a direction from general to specific, as the lead concept appears at the top of the diagram. While the concept map user is reading the map from top to bottom, he/she navigates from the more general to the more specific concepts. The more specific the concepts are, the less explanatory strength they hold. See *Figure 3* for an example and visualisation.

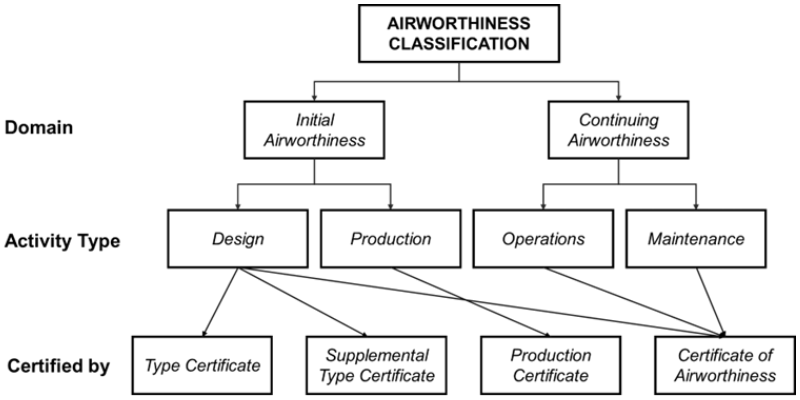


Figure 3: Example of Concept Mapping

Benefits and Challenges

The benefits are numerous as Concept Maps can help students in all aspects of their learning: understanding, interpreting, evaluating, visualising outcomes and presenting. Concept mapping is a useful tool that can enhance the learning experience. However, it is important to consider the challenges associated with the technique, such as the time and effort required to create quality maps.

Table 3: Enhancers and Inhibitors (Concept Mapping)

Enhancers	***Inhibitors***
• *Briefing on purpose and value of mapping* • *Can be used in conjunction with small group work* • *Can be a useful active learning task to recap and connect associated topics*	• *Can require repeated guidance on map construction and use* • *May not be the appropriate tools to show processes, timelines and/or developments* [19]

Implementation

Concept Maps are relatively flexible tools. Due to their flexibility, they can be utilised in a plethora of applications. Their use should be supplementary to a lecturer's teaching e.g., to summarise the lecture's concepts and/or explain challenging and/or misconceived new concepts [19]. A concept map may be designed either by lecturers/ researchers or by students themselves [18], [20]. To build a Concept Map, the user starts with the main concept at the top and proceeds downwards. It can be used in many applications for example, *1.* As teaching tools, *2.* As aids for further learning, *3.* As means of students' learning evaluation, *4.* As feedback mechanism [21].

Step by step implementation:

1. **Identify key concepts:** Identify the key concepts related to the topic. These are the main ideas or themes that you want to represent in your Concept Map and put them in a box or bubble.
2. **Arrange concepts:** Arrange the key concepts in a hierarchy, the main concept goes on the top and follows by sub concepts below, repeat until all key concepts are placed. The concept map would have more general concepts at the top and more specific at the bottom.
3. **Connect concepts:** Use lines or arrows which will represent the relationships between the bubbles/boxes (concepts) and show for the reader the description of each relation using either labels or colours. The arrows/lines can connect any concepts necessary as long as the concepts are placed at the appropriate level.

Additional Links

For free *Concept Map* drawing applications follow the links below:

- Canva
  https://www.canva.com/graphs/concept-maps/
- Miro
  https://miro.com/concept-map/
- Lucidspark
  https://rb.gy/aug85
- VENNGAGE
  https://venngage.com/features/concept-map-maker

For further reading and understanding about *Concept Mapping*:

- Concept Mapping by Cornell University
  https://lsc.cornell.edu/how-to-study/concept-maps/
- Using concept maps in the science classroom
  *http://crisp.southernct.edu/wp−content/uploads/*2016/08/*V anides*$_C$*M.pdf*
- Using Concept Maps to Enhance Understanding in Engineering Education
  https://www.ijee.ie/articles/Vol20-6/IJEE1544.pdf
- Different applications of concept maps in Higher Education
  https://www.jiem.org/index.php/jiem/article/view/290/104

4.3 Feedback

Feedback (*Figure 4*) is a critical component of effective teaching that impacts student behaviour, motivation and achievement [22]. Ultimately the goal of effective feedback is to inform students as to their current performance so that they can improve in future. This is most effective when clearly communicated in the context of the learning outcomes. This can be enhanced through the use of a performance rubric outlined in 4.1. High quality feedback has been linked to increased student achievement, independent learning, resilience and self-efficacy [14], [23], [24].

Outline

High quality feedback has been identified as one of the most impactful strategies in terms of improving student learning outcomes, while also demonstrating strong links to a wide range of desirable beliefs and behaviours [23]. For feedback to show such positive results, it needs to be well received and widely used by students. In order to maximise the value of feedback, the educator needs to consider how students will receive the information related to their performance. Research suggests that poorly constructed feedback can result in negative emotional responses and rejection of the accuracy of the performance evaluation [22]. Several factors can impact this process including the existing relationship between the educator and class, perceived openness, and perceived quality of feedback [24].

To better understand the different types of feedback, firstly we need to understand the source of the feedback as it can either originate from educators, peers, self, automated systems and parents for example. Self- evaluation occurs when a student evaluates their own performance. This is heavily influenced by numerous personal characteristics as well as students' level of expertise within the given topic [25]. It is worth noting that there are many biases which can affect this process, but research suggests the impact of these biases can be lessened through training and repeated use.

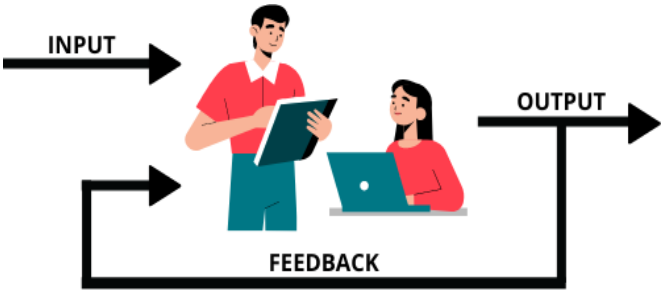


Figure 4: Concept of Feedback

Self-assessment as a process has been associated with increased academic performance and should be considered alongside Metacognition outlined in section 4.4 as it encourages students to consider their own learning processes and performance [22]–[24], [26]. Similarly, peer assessment has been linked with improved motivation, effective self-regulated learning, self-efficacy, and openness to negative feedback [22], [24], [26]. The many benefits associated with high quality feedback go beyond information transmission and should be considered in terms of the student educator relationship which has also demonstrated considerable impact on student outcomes [22], [24]. Shaping students into learners who take responsibility for their own learning, and who can learn to utilise positive and negative feedback, has long term benefits that will continue into their later careers [24], [26]. Once a clear topic for feedback has been established that aligns with the stated learning outcomes, then we can focus on the feedback's content, function and presentation [22].

Research suggests there are 3 primary types of feedback. These need not be separated in their delivery and it is common to provide all 3 within a single instance:

- learning/performance (to enhance students' learning and consequently their performance),
- motivation/affect (to enhance students' motivation and positive learning intentions)
- self-regulated learning (to enhance students' intentions of ownership into their learning) [22].

Benefits and Challenges

The content of the feedback is crucial and includes what is communicated from the source to the students. Content can either be verification (simple statement of right/wrong answers) and/or elaboration (provides more details on the reasons students' answers were right/wrong) [23]. Content

can also vary in moving from general (low number of subcategories) to specific (high number of subcategories). Research supports the use of the minimum number of subcategories possible in an attempt to keep feedback as simple as possible. This selection should happen according to certain conditions: the complexity of the feedback, the students' cognitive level, the level of the subject educational activity [22]. Summarising the above, a list of enhancers and inhibitors of feedback are presented below:

Table 4: Enhancers and Inhibitors (Feedback)

Enhancers	***Inhibitors***
• *Specific and actionable feedback is more likely to alter performance* • *Clear ties to learning outcomes enhances perceived value and increases impact* • *Supporting systems such as rubrics enhance impact and simplify delivery* • *Can be used with peer based assessment systems with appropriate supports*	• *Can require considerable educator time* • *Lack of specificity likely to result in little impact* • *Framing and delivery impacts acceptance and utility* • *Can be heavily influenced by existing class dynamics and perceived value of topic*

Implementation

In 2007 Hattie and Timperley introduced a feedback model that is now widely used. They proposed 3 simple questions to guide anyone who is planning to implement a planning activity [23], [24]. These 3 questions are:

1. **Where am I going?** (This question helps to set the learning goals of the educational activity/task).
2. **How am I going?** (This question aims to compare the students' performance to the learning goals that were set with the previous question).
3. **Where to next?** (This question sets the stage for students' improvement and better achievements in the educational activity/plan) [23].

Also, educators can enhance feedback's effectiveness by carefully considering its focus. For example, feedback can be focused on the result of the task (right/wrong), the task's processes or the learners themselves [23]. In the case of the results of the task, feedback is very effective in the event of students' misconceptions. If students have problems in understanding the taught concepts/procedures, then further lecturing/instruction is recommended instead of giving feedback [23], [24]. In the case of the task's processes, feedback can encourage students to incorporate their own self-assessment phase into their learning. This aspect of feedback can be very beneficial to students' own learning strategies development that will help them successfully proceed in their educational journey, and especially after graduation into their professional practice [23], [24]. In the case of the learners themselves, feedback targeting personal attributes, and not the aspects of their work, is shown to have no positive impact. General comments such as "good job" for example, do not provide any specific information and do not address any of Hattie and Timperley's three questions [23], [24].

Guidelines for writing *Feedback*

Summarising the above, and taking into consideration the relevant literature, a list of guidelines for effective feedback is presented below, as they appear in Schartel, 2012 [23].

- Feedback should focus on the task (promote learning with non-judgemental language focused on the learning activity's actions by providing assessment criteria as examples of acceptable performance) and not the students (praise for performance).
- Feedback should aim to be elaborated.
- Elaborated feedback should be given

in appropriate amount and content.

- Language should be accurate and understandable.
- Feedback should be kept as simple as possible, without compromising level/scope.
- Minimise gaps between learning goals and performance.
- Feedback should be unbiased.

Guidelines for implementing *Feedback*

As far as the feedback system itself is concerned, there are certain guidelines that need to be followed, for feedback to be effective [24]:

- Appropriate (number etc.) assessment/feedback activities into the programme.
- Guidance for students in relation to these assessment/feedback activities, especially their requirements and special features (electronic format, time restrictions etc.).
- Students' accessibility to all assessment/feedback activities' resources (especially online) to facilitate learning ownership.
- Importance and connectivity of the assessment/feedback activities with students' learning.
- Early feedback opportunities into the programme.
- Specifics of students' role into the assessment/feedback activities (active participant).
- Supports in helping students develop their self-assessment skills.
- Supports for staff

For further resources associated with Feedback:

https://www.ul.ie/ltf/resources/2-assessment-and-feedback-blended-and-online-learning

4.4 Metacognition

Research in education has come a long way in describing how we learn and retain knowledge. Based on Albert Bandura's theory, educational researchers have examined how people perceive their learning environment and their role in the learning process. This is called Self-regulated Learning [27], See *Figure 5* for an overview of these factors. Cognition refers to people's abilities to receive, retain and recall information. Motivation is the process that initiates, guides, and maintains behaviours. [27]. The third part of self-regulated learning is Metacognition.

"Going meta"
Connotes becoming an audience for your own performance, that is to say, stepping back to see what you are doing, as though you were someone else actually witnessing it. [30]

Outline

The term metacognition refers to "thinking about thinking" or our ability to know what we know and what we don't know [28], [29]. This human characteristic has been identified and extensively researched within the developmental, instructional, and educational psychology disciplines since the 1970s [30].

This substantial body of research suggests Metacognition is an essential component of effective learning [29] that supersedes intelligence in its significance [31]. Metacognition is the driving force behind independent thinkers and life- long learners who continue to pursue knowledge despite the difficulties that real life might entail [30]. In other words, low achieving students have been identified as having consistently low metacognitive capabilities [30]. Many people are able to develop metacognitive skills independently. But, for those that cannot, metacognitive skills can be developed through practice and instruction [30]. Taking into account the wide range of benefits and its critical role within self-regulated learning, Metacognition is seen as a critical strategy that is worth implementing at all levels of education [32]. However, we need to highlight that the development of metacognitive skills can take considerable time and effort [31].

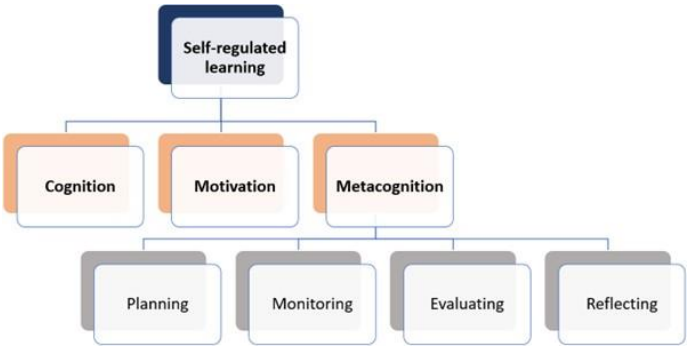


Figure 5: Visualisation of Self-Regulated Learning

Benefits and Challenges

Students with elevated metacognitive abilities tend to learn more effectively and achieve better results in many different areas of study such as science and arts [31], [32]. By developing their metacognitive skills, students can monitor their learning by gaining in-depth understanding of themselves as learners. This means that students gain awareness of their own studying strategies and are successful in using them appropriately throughout their course of study. Metacognitive skills can be developed using specific approaches. Embedding metacognitive strategies into subject instruction has resulted in considerable performance increases [31]. The drawback, when dealing with this concept, is that researchers have not yet agreed on a common definition [32]. This has resulted in researchers focusing on different aspects of metacognition with no clear guidelines for adoption and relevant curriculum development [31]. An important related factor is the meta-cognitive capacity of the educator. If the educator is not capable of meta-cognitive practice it is highly unlikely that they will be able to adequately implement meta-cognitive enhancing strategies [31]. A more detailed list of the known enhancers and inhibitors of Metacognition are presented below:

Table 5: Enhancers and Inhibitors (Metacognition)

Enhancers	***Inhibitors***
• *Metacognitive training and instruction* [32]. • *Associated positive impacts were detected in students' reading, problem-solving and higher order thinking abilities* [31], [32]. • *Students improve knowledge and conceptual understanding* [31], [32].	• *Low meta-cognitive capacity of the educator will likely negatively impact efforts.* • *Professional development for educators is fragmented.* • *No unified presentation of the concept of metacognition by researchers* [32] • *Low levels on educators' own metacognition* [31].

Implementation

As previously outlined, Metacognition has no universally accepted definition. For this reason, educators may encounter competing definitions when considering the broader literature [31]. However, in all cases, educators can include strategies into their teaching to assist with their students' planning, monitoring, evaluating, and reflecting on their educational progress (*Figure5*) [31]. One strategy that has shown considerable success is the use of Regulatory Checklists [27]. Prompts can be provided in the form of questions at key stages of a project or activity. These prompts could be delivered within a lecture or incorporated into an online system to ease collection. Prompt timing and design should be informed by the following categories:

- **Planning** is a very important step in enhancing students' Metacognition as it helps them frame their study activity. The planning step helps them identify the actual nature of the task and what do they need to have at their disposal to achieve the activity (time, strategies, learning sources etc).
- **Monitoring** appears in parallel with the educational activity. Students make sure to understand fully their actions within the educational activity and if they meet the requirements for its successful completion. At the same time, students check their planning requirements and make any adjustments necessary. With the completion of the activity, students need to evaluate both the result and the process of the activity.
- **Evaluation** and **Reflections**, With the completion of the activity, students need to evaluate both the result and the process of the activity. In this step, students need to identify if the activity has been completed successfully and any changes they might needed to do on their strategies and resources. After this step, students can be guided/encouraged to regulate their educational progress with the use of reflection. This process will help them distil their competences and areas for improvement beyond the task at hand and prepare better for future tasks. More details on practical advice on this can be found in the section "Additional links".

Teaching strategies that enhance the students' problem-solving capabilities are often also associated with development of their metacognitive skills [31]. In other words, any strategy that develops the students' knowledge of how to learn instead of just giving them new material to learn, will contribute to the development of their metacognitive skills [31]. These strategies teach students that problems can be solved by following methodical and process centred thinking [31]. Examples of associated activities include team-based activities, mind and concept maps, feedback, self and peer assessment [31].

Additional Links

For further reading and understanding about *Metacognition* it is referred to link below:

- Metacognition by MIT Teaching+ Learning Lab

  https://tll.mit.edu/teaching-resources/how-people-learn/metacognition/

4.5 Self-Assessment

The process of self-assessment relates to activities wherein students engage in value judgements about the quality of the work they have produced. A wide range of activities can be included under the umbrella of self-assessment, from self-grading to more in-depth reflections on their own performance.

Outline

The broad purpose of self-assessment is for students to place themselves in the shoes of an assessor and objectively (insofar as possible) evaluate the quality of their work, or engagement with a process, based on a set of predefined criteria. By engaging in this process, students broaden their understanding of an assessment task and develop an awareness of their own strengths and areas for improvement in terms of their knowledge and skills. This is an important skill for students to possess for effective learning not only in the academic life, but also for their professional development and life-long learning [33].

> "In summary, self-assessment is about students developing their learning skills. …It is not primarily about individuals giving themselves marks or grades. And it is not about supplanting the role of teachers." [69]

Self-assessment is quite commonly linked with self-regulated learning strategies, through which students can develop their skills to work independently and judge the quality of their work in any circumstance moving forward. Assessment, broadly speaking, can be divided into two sub-categories. **Summative assessment**, which aims to evaluate student learning after a period, e.g a course, and **Formative assessment** which aims to monitor student learning and provide feedback to the student during the work as it progresses [34]. It is within this division where debate exists over the impact of self-assessment strategies on overall academic performance, with some suggesting that there can be issues associated with the accuracy of student self-assessment for summative performance. However, with appropriate structure and modelling these concerns can be mitigated.

Benefits and Challenges

Much of the benefits associated with self-assessment strategies rest in the idea that in order for students to make accurate value judgements over the quality of their work, or engagement in a process, they need to develop the necessary procedural and content knowledge in order to make these judgements. By doing this, students will not only develop content knowledge of their subject, but also their ability to monitor and evaluate their own learning. This will help them develop evaluative skills that will be of use beyond their program of study into their future careers. Due to the process requiring students to evaluate their own actions and outcomes it shares some overlap with meta-cognitive strategies outlined in the previous section 4.4.

Table 6: Enhancers and Inhibitors (Self-Assessment)

Enhancers	***Inhibitors***
• *Clear evaluative criteria* • *Supporting rubrics* • *Appropriate instruction and training* • *Feedback on the quality of judgements*	• *Misinterpretation of the task* • *Poorly defined performance criteria* • *Under/Over estimating achievement* • *Absence of modelling the application of evaluative criteria*

Implementation

First of all, the learning outcome needs to be communicated in a clear way to the students. This will help engage students as they take an active role in the learning process and are aware of the learning outcomes. The educator should take a role more like that of a coach, but maintain high expectations because students who believe they can complete the task are more motivated to engage [35]. There are many ways in which self-assessment can be implemented, however there are a number of common

features associated with any implementation [36]:

1. **Where to use:** Before educators would like to implement self-assessment, they must first identify which part of their course/program they will implement self-assessment in. In making this judgement consider students' prior knowledge and if possible whether or not they have engaged in self-assessment before. If this is your first time implementing it, it would be worthwhile doing so with a less complex activity/task.
2. **Teach students about self-assessment:** Begin by teaching students about self-assessment, what it is, and how it can help to improve their learning. Explain the purpose and benefits of self-assessment and provide examples of how it works.
3. **Set clear learning goals:** Clearly define learning goals that you want students to achieve. Make sure that the goals are specific, measurable, and achievable. This can be supported with the use of a rubric (See section 4.1) to help students evaluate their work.
4. **Provide feedback:** Encourage students to reflect on their work and give themselves feedback. Provide prompts or questions to help guide their reflection. Also, provide feedback as a teacher to help students identify areas of improvement. Ideally students should have an opportunity to apply feedback in a future version of an assignment or similar task.
5. **Use self-assessment tools:** There are various self-assessment tools available that students can use to evaluate their own learning, such as journals, portfolios, self-assessment checklists, and peer feedback. Choose the tools that best suit your teaching approach and the learning goals of your students [36].
6. **Encourage self-reflection:** Encourage students to reflect on their self-assessment and use it to set new learning goals. This will help them identify their strengths and weaknesses and create a plan for improvement.

Consider implementing this as a mid-way check to a summative assessment so that students have the opportunity to implement the outcomes of their self-assessment and improve upon their work. It is also important to create a supportive learning environment where students feel comfortable sharing their self-assessment results with you and their peers.

Additional Links

Additional resources related to *Self-Assessment*:

- Self-assessment by Trinity College Dublin:

  https://www.tcd.ie/academicpractice/Assets/pdf/Academic%20Practice%20Resources/Guide%20to%20Student%20Self%20Assessment.pdf

- 7 strategies for introducing self-assessment in your classroom:

  https://theeducationhub.org.nz/7-strategies-for-introducing-self-assessment-in-your-classroom-2/

- Strategies for student self-assessment:
  https://education.nsw.gov.au/teaching-and-learning/professional-learning/teacher-quality-and-accreditation/strong-start-great-teachers/refining-practice/peer-and-self-assessment-for-students/strategies-for-student-self-assessment

4.6 Jigsaw-Learning

The teaching and learning strategy commonly referred to as "Jigsaw" or "Jigsaw Learning" can be considered a method of cooperative learning. Cooperative learning is a student-centred, active learning approach where students work together in groups to accomplish shared learning goals. Worth mentioning is that an exercise can only be considered a cooperative learning activity if the following five elements are present [37]: *1.* Positive interdependence, *2.* Individual accountability, *3.* Face-to-face promotive interaction, *4.* Appropriate use of collaborative skills and *5.* Group processing.

Outline

Jigsaw learning is a strategy that encourages students to work together in small groups to master a particular topic. In the classroom, students work in teams to complete a complex task or solve a problem by sharing information and teaching each other what they have learned. Each student in the group is responsible for mastering a particular portion of the material and then teaching it to their group members. Jigsaw is performed in groups as mentioned above and each member of the group can only achieve their goal when all other members have achieved theirs [38], These groups are referred to as jigsaw groups. Each member gets help from an expert group, which consist of others with the same goal, to achieve their goals and then report back to the jigsaw group for discussion (*Figure 6*).

The principles of jigsaw learning include creating a cooperative learning environment where students take responsibility for their own learning and are actively engaged in the learning process. Jigsaw learning aims to foster a sense of community in the classroom by encouraging students to work together and help each other. The key principles of jigsaw learning include breaking down complex topics into manageable parts, assigning responsibility to individual students, and promoting collaboration and communication among students. This approach creates a supportive and inclusive classroom environment where all students can contribute to their fullest potential.

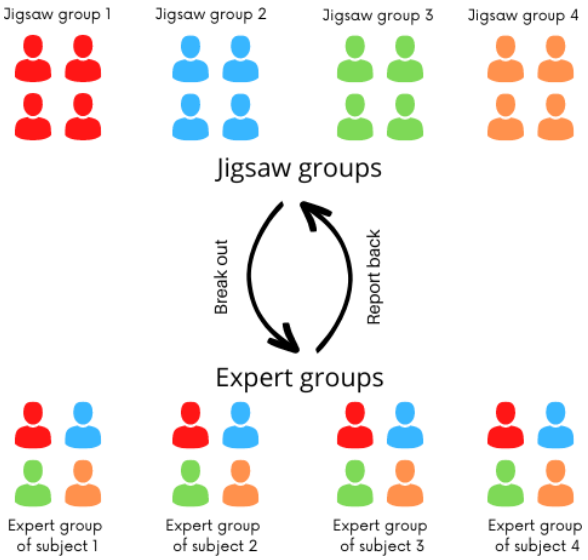


Figure 6: Visualisation of Jigsaw learning.

The jigsaw learning approach to cooperative learning was developed by Elliot Aronson [39] and his students in the 1970s. The approach was designed to help students to breakdown topics into more manageable sections, and for students to then teach each other the piece they have mastered, consequently combining these pieces into one whole [40].

Benefits and Challenges

The research shows that jigsaw learning provides many benefits for students [40], [41]. Some of the reported benefits are: *1. Increased student achievement*, *2. Enhancing self-esteem*, *3. Positive student attitudes* and *4. Develops Teamwork skills* such as communications skills, conflict management skills, time management and critical thinking. Listed below are some enhancers and inhibitors for the method *Jigsaw learning*, which can be good to take in consideration when implementing the method.

Table 7: Enhancers and Inhibitors (Jigsaw-Learning)

Enhancers	***Inhibitors***
• *Small groups of between 4 and 6 (Depending on activity)* • *Ensuring students are divided in groups with varying ability, gender, ethnicity and race.* • *Ensuring the five elements listed earlier are present (Positive interdependence, Individual accountability, Face-to-face promotive interaction, Appropriate use of collaborative skills and Group processing).* • *Supporting resources such as handouts that represent a section of the overall topic*	• *Failure to follow the outlined structure can lead to social loafing (Members who disengage).* • *Numerous different (unvetted) informational sources may lead to confusion and conflicting conclusions*

Implementation

Cooperative learning strategies can be implemented in a variety of situations such as a class or lecture. Cooperative learning can be effectively implemented at all levels of education including primary, secondary and tertiary level. In the following example the steps to complete the jigsaw learning method will be discussed.

Jigsaw learning steps:

1. **Introduce the strategy and the topic to the students.** Before beginning the jigsaw activity, it is important to introduce the strategy to the students and explain the purpose of the activity. This can help to set expectations and ensure that everyone understands their role in the process.
2. **Assign each student into groups of 4-6 students.** Ensuring students are divided in groups with varying ability, gender, ethnicity and race. These groups are referred to as the jigsaw group. It is important to create groups with a diverse range of students to ensure that everyone has an equal opportunity to participate and learn from one another. Each group member will be responsible for learning a different aspect of the task.
3. **Appoint a member of each group as a group leader.** The group leader will be responsible for organizing and facilitating the group's activities, as well as ensuring that everyone has an opportunity to participate and contribute.
4. **Determine a set of reading selections and assign one selection to each member of the group.** Each student will be responsible for learning a different aspect of the task. This can help to break down complex task into manageable pieces and allow students to focus on one specific area of the task.
5. **Set time limits on each student task step.** To ensure that the activity stays on track and that students have enough time to complete each task, it can be helpful to set time limits for each step of the activity.
6. **Give students time to familiarise themselves with their assigned reading.** Students should be given time to read and understand their assigned reading before moving on to the next step of the activity.
7. **Allow members of each group with the same reading to discuss the reading. These are referred to as expert groups.** Once students have read and understood their assigned reading, they should meet with other students who have been assigned the same reading. This can help to deepen their understanding of the topic and allow them to discuss any questions or areas of confusion.
8. **Provide key questions to help the "expert groups" gather information in their particular area.** To guide the discussions in the expert groups, it can be helpful to provide a set of key questions that each group should try to answer. This can ensure that all groups are focused on the same aspects of the topic.
9. **Bring students back to their jigsaw groups.** After the expert group discussions, students

should return to their jigsaw groups to share what they have learned with their peers.

10. **Ask each student to present his or her reading to the group.** The group leader will be asked to take charge, organizing both timing and sequence of presentations. After the expert group discussions, students should return to their jigsaw groups to share what they have learned with their peers.

Additional Links

For further reading and understanding about *Jigsaw learning* it is referred to links below:

- Jigsaw learning by Social Psychology Network

  https://www.jigsaw.org/overview

- Cooperative learning by Ako Aotearoa – The National Centre for Tertiary Teaching Excellence

  https://ako.ac.nz/

4.7 Inquiry-Based Learning

The last decade has seen the rapid development of specialised approaches that are particularly suited to the STEM disciplines. New methods have been introduced to promote students' learning and fill in the gaps of traditional teaching methods. Inquiry-based learning has become particularly popular within science but is increasingly being used within engineering programs.

Outline

STEM courses are about scientific questions, experiments, trials and projects that value applied student experience. In many ways these practices reflect the values of the related STEM professions and seek to mimic future career scenarios. Across disciplines, students who engage in active learning activities that result in dynamic experiences report higher levels of motivation, engagement, resilience and perceived value for the topic being taught [42], [43]. Inquiry-based learning is a form of active learning and seeks to encourage real world connections in response to a discipline specific question or challenge. This typically involves the student seeking relevant information independently. Lee et al. [44] defined inquiry-based learning as an "array of classroom practices that promote student learning through guided and, increasingly, independent investigation of complex questions and problems, often for which there is no single answer".

Inquiry-based learning
is an approach in education that places the student in the centre, through curiosity and questioning.

The introduction of Information Technology (IT) (e.g laptops, smartphones, etc..) into education, has speeded up the need to support inquiry-based learning even further. Mainstreaming computer technology in higher education has provided the means to make STEM education even more accessible with multiple new applications, and this access to increasingly vast amounts of data has highlighted the need to develop the types of independent answer seeking capacities that are supported within Inquiry-based strategies [42], [43]. By supporting inquiry-based learning, we are supporting students to act under their own initiative and encouraging them to discover knowledge through this active approach [43]. Inquiry-based learning is a teaching strategy that is employed when educators are looking to implement an active learning approach into their teaching. Students are given the opportunity to explore their curiosities about the topic. It's about to actively engage the students in their own learning. Inquiry-based learning can be used with groups or individual students. While students should be free to pursue knowledge in response to a proposed question/challenge, it can often be useful for the educator to suggest some high quality reliable initial sources of information.

Educators need to evaluate whether their educational system supports inquiry-based learning and develop their own familiarisation with the methodology through training and support. Educators need these resources as they will have to also consider requirements such as their students' needs and capabilities in parallel to their change of role (from a traditional instructor to a project facilitator) before deciding on the extent, design and use of the strategy [45].

Benefits and Challenges

Research suggests that inquiry-based learning leads to greater knowledge retention, skill development, independent learning and overall improved academic performance [43]. Also, researchers have investigated the way IT resources have interacted with inquiry-based learning and which specific aspects have benefited. Conclusions from such projects showed that IT applications have been beneficial, especially to students' research related skills such as: problem collection and analysis, results and conclusions' synthesis and presentation [43]. A more detailed list of enhancers and inhibitors of inquiry-based learning are presented below:

Table 8: Enhancers and Inhibitors (Inquiry-Based Learning)

Enhancers	***Inhibitors***
• *Supporting initial resources such as vetted readings or databases* • *Clear success criteria aligned with learning outcomes* • *Encourages students' participation.* • *Initial guidance in specific search techniques*	• *Poorly defined initial questions/challenges can lead to frustration and disengagement* • *Lack of basic training in essential techniques* • *Lack of feedback/guidance in the early stages could result in disengagement for less experienced cohorts*

Implementation

The *Inquiry-based learning method* is a cyclical process, for educational purposes, can be broken down into simpler steps. Several such cyclical processes have been introduced to represent inquiry-based learning. The most used ones are the following two: the **5E cycle** and the **White and Frederiksen inquiry cycle**. Both cycles are constructed by 5 inquiry phases each. Their difference is that one is used to develop a new theory (inductive) while the other is used to test an existing theory (deductive) [43].

5E cycle is an inductive process thus used when developing new theory based on observations. The five inquiry phases are listed below: [46]

- **Engagement:** Students are engaged in a challenging situation. This phase should create a desire to explore the topic. The teacher is not intended to lecture or provide explanations in this phase.
- **Exploration:** Students must use their prior knowledge to create ideas, understand the concept. It's in this phase the learning of students will enhance.
- **Explanation:** In this phase the educators have a major roll. The students and educator will sort out any misconceptions that the students have about the topic/concept from the previous phase. The educator may provide deeper information about the topic if necessary.
- **Elaboration:** Students are encouraged to apply their new understandings and knowledge in the topic/concept.
- **Evaluation:** In this phase the students are encouraged to evaluate their abilities and under- standing. Educators also give an opportunity to evaluate the students understanding.

White and Frederiksen inquiry cycle is a deductive process thus used when testing an existing theory with observations. The consisting parts are: [47]

- **Question:** In this phase the students will define a research question, which will allow them to do a simple experiment. This can be a difficult for undergraduate students and should be scaffolded.
- **Predict:** The student will when predict what they think will happen, this will engage the students.
- **Experiment:** The student will perform the experiment to try to solve the defined question. The experiment can be implemented in several way, e.g., Simulations, real world experiments.
- **Model:** In this phase the students will analyse the results from the previews phase and use their prior knowledge to reach a solution to the defined question.
- **Apply:** The students are encouraged to apply and analyse their solution to other similar topics.

Inquiry-based teaching strategies are not very simple to implement as they need time and effort invested in their inception, design preparation and implementation. The good news is that multiannual research in the area has resulted in multiple relevant publications, conferences, training and teaching community spaces that provide relevant material and training to educators. These useful resources provide support

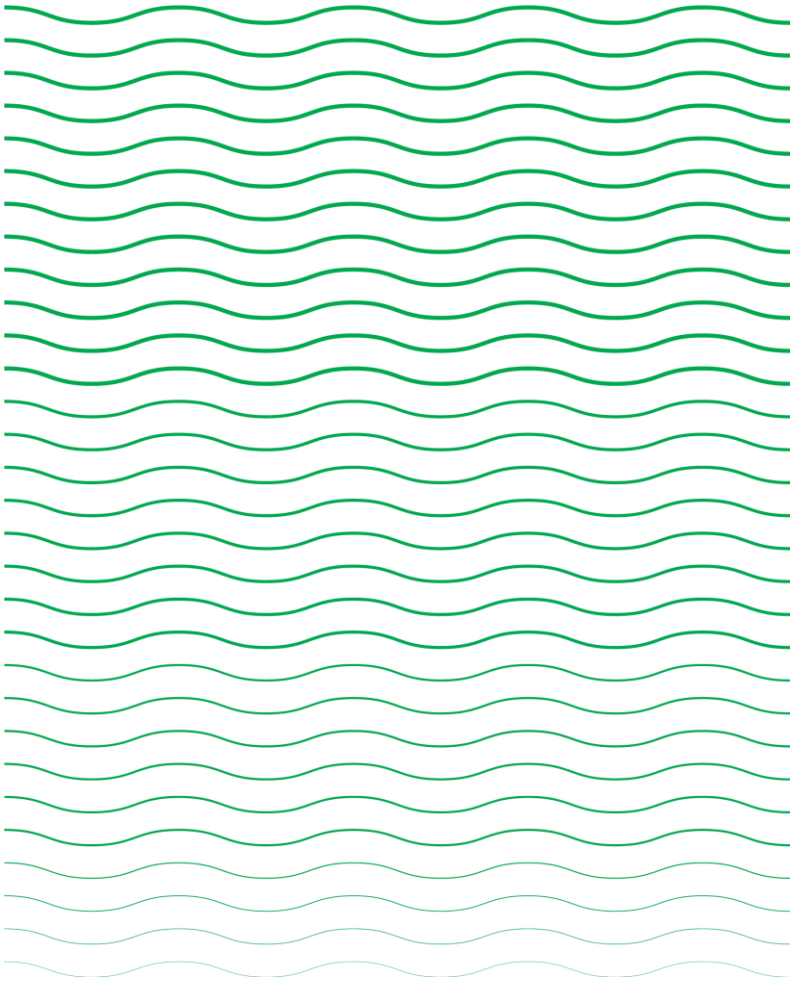
and experience to every educator willing to integrate enquiry-based learning in their teaching.

Additional Links

For further reading and understanding about *Inquiry-based learning* it is referred to links below:

- Inquiry-based learning by Queens University

  https://www.queensu.ca/ctl/resources/instructional-strategies/inquiry-based-learning
- Inquiry-based learning by the Academy of Inquiry Based Learning
  http://www.inquirybasedlearning.org/



Chapter 5
Factors

5 Factors

Factors are broader influences on learning outcomes in lectures, tutorials and laboratories. These can include student motivation, socio-economic status, beliefs related to capability as well as many others. Some factors can be directly influenced by educator actions while others are less malleable, but developing a basic understanding of their influence can inform your approach and design decisions. By modifying your approach, you can lessen the negative impact of these factors and enhance their positive impacts.

5.1 Motivation

Motivation is one of the most important human characteristics and is defined as: "*Powering people to achieve elevated levels of performance and overcoming barriers in order to change*" [48]. Motivation is the force that enables humans to act the way they do in order to achieve goals. As educators our essential purpose is to get students to engage in activities that will result in the development of knowledge and skills. Motivation is inherently linked to this purpose and should be considered by all educators.

Outline

Motivation is applicable from a very young age and is a critical factor within the educational arena. Learning is an active process and requires self-directed effort which is heavily influenced by a student's motivation. In an ideal educational system, Science, Technology, Engineering and Mathematics (STEM) educators would like to interact with students that have genuine interest in STEM programmes. Such highly motivated students tend to require little persuasion to persist and excel within their programs [49]. Literature suggests that students who report higher levels of motivation, are more efficient problem solvers and achieve improved learning outcomes [49]. However, the development of high levels of motivation is complex and can be influenced by many external factors including past performance, goal orientation and feedback systems.

Self-Determination Theory includes some of the most widely used motivation constructs in educational research. According to this theory, there are two types of motivation (*Figure 7*): **A. intrinsic motivation**, interest that come from within us (for example, inherent joy in the task and interest in the bigger questions) and **B. extrinsic motivation**, interest provoked from an outside source (e.g., promise of a reward, avoidance of punishment). Recent debates around the nature of motivation suggest that this may be a rather simplistic interpretation of this complex topic. However, there is broad agreement that student motivation can be impacted by educator actions and that elevated motivation levels are linked to a wide range of positive outcomes [50]. For the sake of pragmatism and brevity this section will not focus on these theoretical debates, and instead focus on how you can influence this factor.

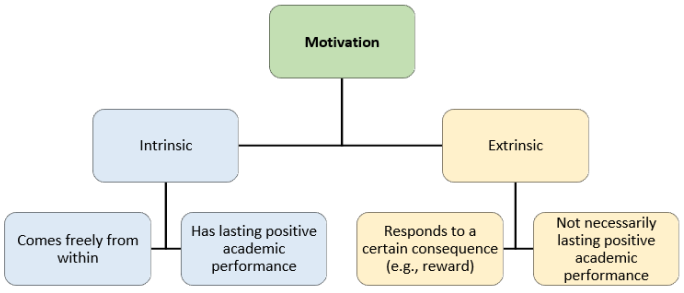


Figure 7: Visualisation of the Self-Determination Theory from Deci and Ryan

Intervention

When dealing with intrinsic motivation, educators should take steps not only to initiate students' motivation to actively engage with the programme's material, but also to maintain this motivation [51]. The first and most crucial step towards this direction is to support the students' natural curiosity, as it initiates their willingness to learn. In order to do that, educators need to understand their students and the type of motivation each one of them might already have. Investigating motivation in education can be more complicated. In education the students' goals can be quite diverse; students study to gain high grades at a test, master a certain skill or graduate with high enough grades to get a well-paid job. They

also put effort into their studying because they gain satisfaction from the learning process itself, they expand their own knowledge, and have an interest to critically evaluate the work of others [51].

It is well understood that it is much easier to teach students already motivated in their study area, as these students will be more successful in understanding, learning, and retaining the taught material. The challenge lies with the unmotivated ones, as there are many questions still to be answered on how to promote motivation to uninterested students [51].

Many theories have been proposed about motivation, however most of them appear to have certain limitations that prevent them from being widely used. Listed below are some tips that are used in general:

- Delivering the material at a level and pace that matches the cognitive level of students and consequently is meaningful to them, is a good start [51].
- Educators need to provide a supportive and safe learning environment that prioritises learning over performance [51]. By doing this, educators promote meaningful learning that creates knowledgeable learners that are equipped to successfully face any assessment challenge.
- Educators needs to understand their students' motivational characteristics and be aware of the impact of their chosen strategies and course design [51]. Use of strategies that promote social interaction, allow students to demonstrate their progress and relevance of the topic to future goals have been linked to increased student motivation.

Therefore, the challenge here for educators is to communicate the relevance of the chosen topics to students future goals. This could include links to other topics within the semester, or focus on broader relevance to future career based goals.

5.2 Self-Efficacy

STEM education is an outcome-based field. This means that advances in research and practice depend greatly on the quantity and quality of knowledge and the skills obtained by graduates. Among other factors examined in this part of the guide, self-efficacy is one that contributes greatly to the students' learning process. Self-efficacy is one of many personal beliefs, introduced by Bandura in 1977 [52] as "one's capabilities to organise and execute the courses of action required to produce given attainment" [52].

Outline

Self-efficacy is about the human characteristic of self-reflection, a mechanism that allows students to assess and transform their conception and behaviour [52], [53]. This mechanism is possible as self-efficacy enables students to foretell how they are going to act upon already learned behaviours and the amount of learning they are capable of [52], [53]. Within the online learning context, self-efficacy is expanded beyond the learning classroom to include all technological artifacts required for the online learning [54]. Therefore, the element of online learning provides additional challenges as it adds the element of "use of technology" to the learning process itself; nonetheless the principles remain the same [54]. However, one thing that needs to be highlighted here is the differences that the two genders (male and female) show regarding self-efficacy and the use of technology as women appeared to have lower technology and STEM academic self-efficacy than males [55].

Educational research has shown that students' self-efficacy can influence their motivation and learning [52], [53]. This is evident in the way the students interact with all aspects of their courses e.g., types of assignments/projects they choose, the amount of effort and time they put into the various activities of a course, and their persistence in achieving goals [52], [53]. The stronger self-efficacy students have, the more empowered they get to increase engagement in their educational activities. This relationship between strong self-efficacy and empowerment also helps them create positive feelings in the process. Students who have weak self-efficacy, tend to exaggerate the difficulties of tasks and get overwhelmed by negative emotions such as powerlessness and depression [52]. Therefore, when discussing aspects of students' motivation and learning, we need to keep in mind that both are regulated by self-efficacy (*Figure 8*). So, if we measured students' self-efficacy, then we would be able to predict and even enhance their motivation and learning [52], [53].

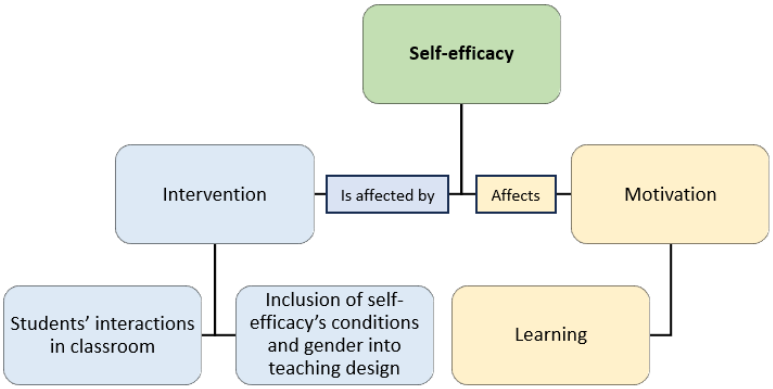


Figure 8: Visualisation of Self-Efficacy

Intervention

In order to design efficient intervention measures to enhance self-efficacy, first we need to understand the theory behind it. Students' self-efficacy is regulated by four conditions: their *enactive mastery experiences*, *vicarious experiences*, *social persuasions* and their *physiological and psychological states* [52]. Researchers have investigated if and how these conditions could affect self-efficacy. Findings of these research activities indicate that interventional treatments that follow the principles outlined in this chapter, are very effective in influencing student's self-efficacy [52].

- **Enactive mastery experiences** (when they have dealt successfully with a certain situation) appear to be the one that is very strongly associated with creating robust self-efficacy. This finding suggests that prioritised practical experience for students allows them to put the learned theory into practice and gives them the opportunity to gain successful/positive experiences,

especially for demanding tasks. For this condition to be used successfully in the influence of self-efficacy, it is advised that the students' cognitive level, the authenticity of the tasks and the supervision level are to be closely monitored while designing the practical experience tasks [52].

- **Vicarious experiences** (experiences they gain by observing others, especially others that are of similar circumstances and their output can be very easily compared to their own capabilities) this condition is identified to influence students' self-efficacy, research is not concluded yet on whether it is the peers or expert models' exemplar behaviours that are the most influential [52].
- **Social persuasions** (when students receive encouraging and empowering to their abilities information, especially when it is genuine and coming from reliable and respected individuals) or specific verbal persuasions, in higher education, can also take the form of feedback that is given to students. Research has not decisively indicated feedback to strongly influence self-efficacy. However, when these factors are considered at the educators' level (teaching strategies) and the students' level (interactions in the classroom), a greater influence at students' self-efficacy is observed [52].
- **Physiological and psychological states** (physical and psychological state of students is very important as they affect their self-efficacy accordingly) such as gender is a factor that should not be overlooked while designing interventional measures. When self-efficacy was compared between genders in same setting, females appeared to have lower technology and STEM academic self-efficacy than males, while actual performance was similar for both genders. Therefore, in this instance, lower self-efficacy for females did not indicate lower actual performance [55].

5.3 Stereotype Threat

Individuals have certain cognitive characteristics that help us cope with everyday life. Stereotypes are among them. Stereotypes are the set of characteristics that our society has linked with all individuals that belong to certain groups of people and social categories. They help us save time by reducing the time we need to process any new information that comes in regarding other people's standing and behaviours. However, they can often lead to inaccurate judgements related to an individual's capacities or suitability for a particular role.

Outline

Having the stereotypical characteristics in mind, we tend to categorise individuals according to our preconceived ideas regarding a group that they below to. This can be based on socio-economic status, gender, ethnicity etc [56]. However, the trap in this process is that stereotypes are by their definition overgeneralisations. Not all characteristics can be linked to each individual member of the group; for this reason, by following the stereotypical approach we often do not make the correct judgement [56]. We are frequently not fully aware of our stereotypical beliefs and biases, but these factors can heavily influence our students learning experience and out performance as educators.

> "The responsibility for counteracting stereotype threat does not rest solely on the targets' shoulders; rather, educators, researchers, and policymakers need to start taking proactive steps to remove the threat in the air." [63, p. 429]

Therefore, taking action based on these preconceived beliefs could lead to poor strategy selection, goal setting and assessment practices [57]–[59]. Engineering education is no exception to this phenomenon. When dealing with students, these inaccurate beliefs tend to put groups of students under pressure to disprove these perceptions; and this additional pressure might not help to meet their full potential [57]–[59]. For example, gender based beliefs around mathematical ability have been found to be inaccurate, but to have severe impacts on females motivation and performance within the subject [56]. Stereotype threats have been observed to have potentially negative impact on vulnerable and minority groups' educational development, among other areas within our social structures [57], [58]. This can be explained partly as stereotype threats have been found to affect a person's cognition. If a person is under this predefined state, not only can they underperform in both cognitive and physical activities and tests, but also can undermine their learning [57]–[59].

In particular, research has indicated that stereotype threats are more evident on academic material that is challenging and considered more difficult for students [58]. Vulnerable students tend to avoid challenging situations that even though they facilitate learning, their difficulty might provide increased risk for failure and embarrassment for them. For this reason, academics would need to reduce the stereotype threats for these students; this practice will encourage students to not fear disappointment in difficult academic activities and actively engage with the class while asking for additional help/support [58].

To reduce stereotype threats, lecturers can select any or all of the proposed intervention measures, as they are proposed in the next section.

Intervention

To reduce stereotype threats, it is important that any intervention should take place before the learning activity. The timing for this to happen is crucial, as stereotype threats need to be reduced before the actual learning and knowledge gain has occurred [59]. Research has shown that these three concepts below reduce stereotype threats:

- **Value affirmation** If vulnerable students are exposed to even a brief value affirmation intervention to overcome the relevant examination stress, their performance is enhanced. Value affirmation is an activity that promotes students' feelings of integrity and self-worth in a learning environment. Therefore, value affirmation is a technique that can be used to mitigate negative stereotype threats' impact on students' academic performance [58]. Such brief interventions, given that they start early

and continue to be implemented throughout students' academic lives, can have positive long-lasting effects [58].

- **Teaching material** and any information delivered to a class should be free from any content that might promote stereotype threats. This material and information should be fair to all students of the class and any negative stereotypical information should be taken out [59]. These issues can be subtle in nature and often linked to existing imbalances within the profession, such as only including male examples of significant contributors to the field.
- **Anonymising modes of interactions** This can help students to express their opinions, ideas, knowledge without the fear of being judged or been perceived according to the negative stereotypes by others [60]. Online teaching tools for example, can meet this purpose as they can be set to provide such conditions and allow students to express themselves away from any stereotype threat. Such an example is the use of Wikis, web based interactive collaborative space which can be used for knowledge sharing, collaborative writing, and inquiry discussion. Being pedagogically neutral, they are used extensively in higher education, as they meet multiple purposes and keep students' anonymity at the same time [60].

5.4 Gender and STEM

Research examining under representation of groups, especially women, in STEM areas of work and study has increased over the past years. Research efforts continue to gather momentum, committees have been established, regulations have been drafted and imposed, advertisement campaigns and outreach activities have been launched. All these measures have one goal: to encourage greater levels of female participation in STEM.

Outline

Historically, STEM fields have been male-dominated, and there are still significant gender disparities in STEM education and careers, e.g women with a degree in STEM earns between 13-18% less than a male with the same degree [61]. STEM programmes still welcome fewer female than male students in their classrooms, even after all these activities and measures about enhancement of the female representation in STEM. To understand better this phenomenon, let's explore the context of the Irish students' opinions on which gender matches better with STEM programmes.

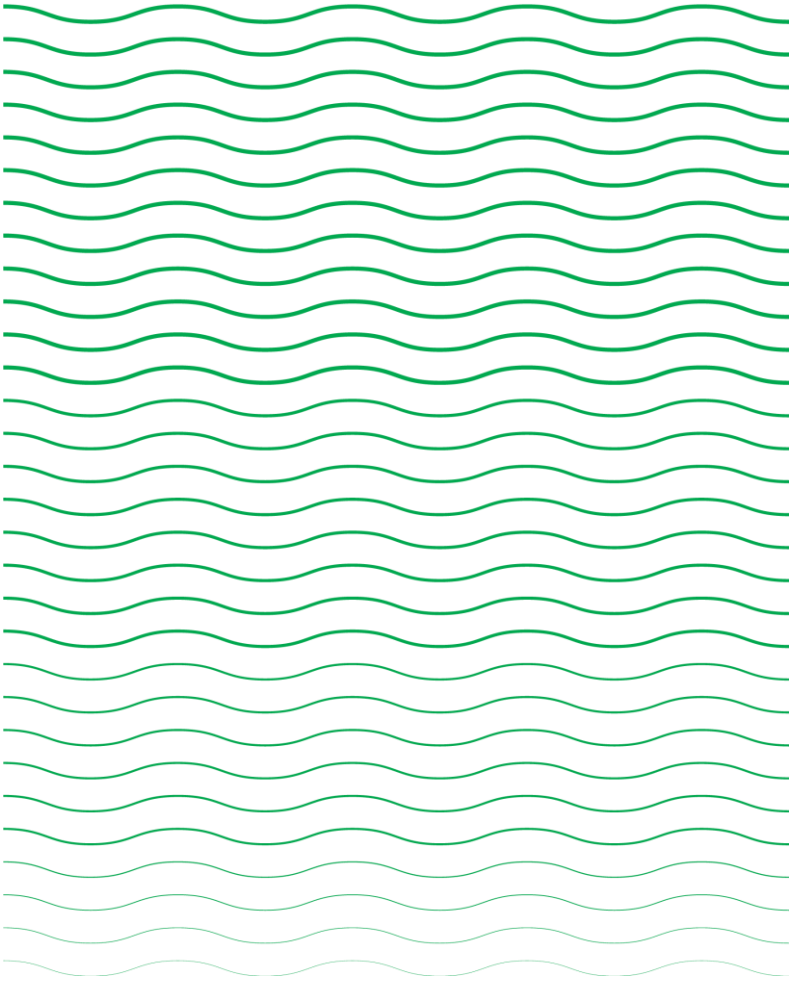
Third level education (University) should not be considered in isolation; the majority of undergraduate students come directly from secondary level (high school). Therefore, what happens within the second level education system has a considerable impact on the opinions, values and capabilities of the students that enter our programs A recent 10-year, large scale project in Ireland revealed that female pupils were treated less favourably than male pupils in Mathematics by teachers and parents alike [62]. Mathematics is used as a strong indicator in third level students' success because there is a strong association between high scores in Mathematics and success in third level degrees [63]. Such behaviours and attitudes can influence female pupils to select more gender typical areas of study and work, away from STEM. So, there is no surprise that less than 25% of STEM workers in Ireland are women, and these women have had to develop specific coping mechanisms to overcome gender biases. A recent Irish study that was conducted among Irish third level students confirmed the situation, as described by O'Brien [62] with only 22% of the female participants studying at a STEM third level programme [64].

In many STEM classrooms it is common to still use traditional teaching methods, these are more individualistic and competitive. Research suggests that these techniques are more effective for male students. Research has also shown that both genders prefer collaborative and cooperative environments over competitive [65]. This can indicate that the teaching methods needs to be updated and this guide can be a tool for doing so.

An increased representation of women in STEM can enhance talent, productivity and progress, an opportunity that cannot be missed [66]. The long term international project Implicit [67], a project that is collecting data since 2003 with more than 600,000 participants, suggests that trends observed within the Irish based studies are similar to those observed across Europe.

Intervention

Literature indicates that intervention is mostly institutional [68]. This means that universities have the resources and system in place to prepare accordingly and make female applicants and students feel welcome into STEM. Having budgetary allocation towards such interventions, a university can establish a functioning mechanism in promoting and retaining female students [68]. A perfect example of such intervention is the Athena Swan charter, a multinational initiative for gender equality. Academic staff who would like to empower women and underrepresented groups in STEM could familiarise themselves with their institution's initiatives and campaigns and get involved. By supporting an institutional effort, academics can influence their institutional action plans and therefore maximise their efforts. Beyond this approach, each academic can make his/her personal contribution to address this issue. Having and following own personal unbiased practises and using institutional resources to support female students can be beneficial in the classroom as well.



Additional Information

6 Additional Information
6.1 Autor Details

Project lead

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Jason Power currently leads an EU funded study that aims to enhance evidence-based practice within third-level STEM learning environments. Within this, and related nationally funded projects, he is leading an international team in the creation of professional development programs, synthesised evidence bases and associated supporting resources. His previous research has focused on non-cognitive factors and their relationship to performance within STEM learning environments.

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6.2 Abbreviations

Abbreviation	Meaning
E-guide	Electronic Guide
E-Book	Electronic Book
STEM	Science, Technology, Engineering and Math
EU	The European Union
UL	University of Limerick
IT	Information Technology
RWTH	Rheinisch-Westfälische Technische Hochschule

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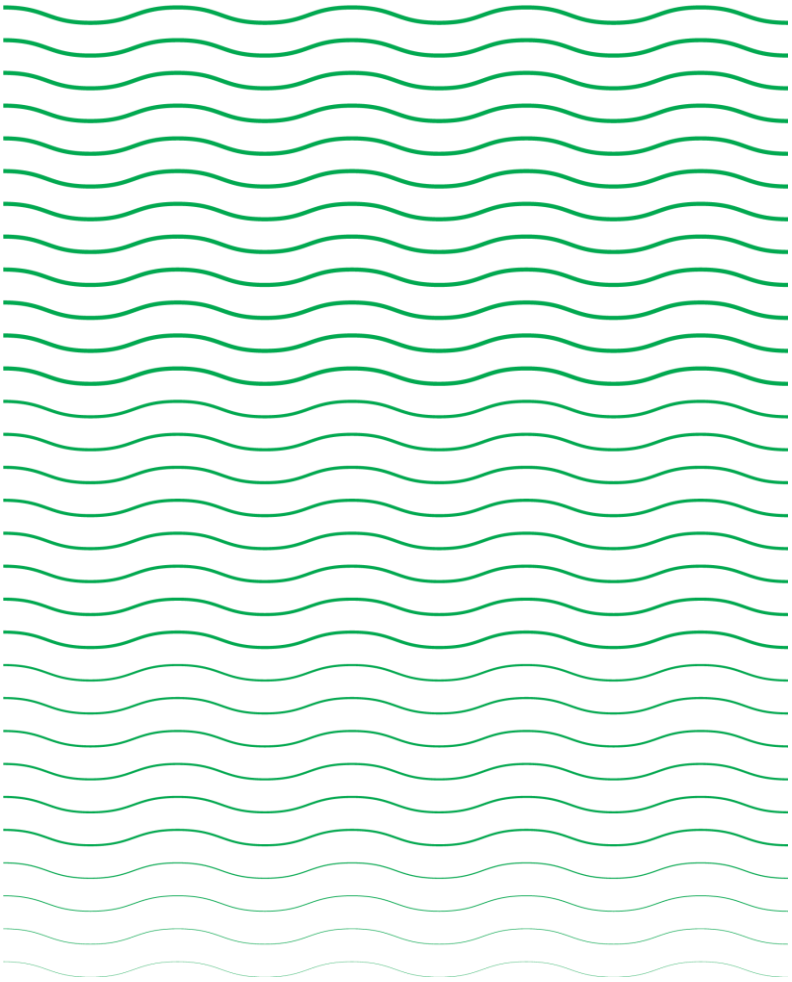

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