TIP SHEET

The Five Building Blocks of Next Engineers

Overview

The purpose of Next Engineers is to increase the number and diversity of young people pursuing engineering career paths. This document describes the five essential building blocks to becoming an engineer and provides evidence for the inclusion of each block. It is important to note that while five discrete building blocks are presented, there is significant interplay between them.

1 Awareness

For Next Engineers, awareness is knowing that engineering as a field and career exists and realizing that engineering is something 'people like me' do and is something that 'I' could do. It is having knowledge of the **different types** of engineering careers available, the kind of **work** engineers do, and **how** they do it.

To begin to consider a career in engineering, students must be aware of the field, of careers available in the field, of what people in these careers do, and how they do it.

Awareness
A perception or knowledge of something.

https://dictionary.apa.org/awareness

2 Interest

For Next Engineers, interest is possessing a **positive outlook** and **attitude** towards engineering as a profession, placing **attention** on engineering as a possible career and a **curiosity** to learn more about engineering. It is a motivation to **actively pursue** engineering as a career.

To decide to pursue an engineering career, a student must first have an interest in it and feel a desire to dedicate the time and attention to the goal.

Interest
An attitude characterized by a desire to give selective attention to something of significance.

https://dictionary.apa.org/interest

3 Engineering Habits of Mind

A 'habit of mind' means "having a **disposition** toward **behaving intelligently** when confronted with problems" and **valuing** "one pattern of thinking over another" implying "**choice making** about which pattern should be employed"[1].

> *"**Intelligence** is the habit of persistently trying to understand things and make them function better. Intelligence is working to figure things out, varying strategies until a workable solution is found... One's intelligence is the sum of one's habits of mind.*
>
> — ***Lauren Resnick***[a]

[1] "What Are Habits of Mind?", The Habits of Mind Institute, accessed 23 October 2021, https://www.habitsofmindinstitute.org/what-are-habits-of-mind/

[a] Resnick, L., "Making America Smarter", Education Week Century Series 18, no 40 (1999): 38 – 40. Available at https://www.edweek.org/policy-politics/opinion-making-america-smarter/1999/06 (accessed 23 October 2021)

Building off the work on general habits of mind by Art Costa and Bena Kallick , mathematical habits of mind by Al Cuoco[3] and scientific habits of mind by Colin Gauld[4], Muammar Calik and Richard Coll[5], the Royal Academy of Engineering and the Centre for Real-World Learning, developed and validated six *engineering-specific* habits of mind[6]. These are:

- Systems thinking
- Problem-finding
- Visualizing
- Improving
- Creative problem-solving
- Adapting

See Annex A for an explanation of each.

Developing these engineering habits of mind is a necessary part of learning to **think** and **act** like an engineer and will help to **equip** and **empower** students on their journey to becoming an engineer and prepare them for the rigors of post-secondary engineering education.

Habits of Mind
The Habits of Mind are an identified set of 16 problem solving, life-related skills, necessary to effectively operate in society and promote strategic reasoning, insightfulness, perseverance, creativity, and craftsmanship.

https://www.chsvt.org/wdp/Habits_of_Mind.pdf

4 Engineering Identity

For Next Engineers, an engineering identity is a particular role identity[7] that students develop during their experiences in an engineering community of practice and engaging with the process of engineering, and which helps them to see themselves as 'belonging to' or as legitimate members of the community.

Formation of this identity is important in generating a desire to pursue an engineering career and in fostering greater **resilience for engineering learning**. Indeed, an engineering identity has

Identity
Who you are, the way you think about yourself, the way you are viewed by the world, and the characteristics that define you.

[2] Costa, A. and Kallick, B., "Discovering and Exploring Habits of Mind", Alexandra, Virginia: Association for Supervision and Curriculum Development (2002).
[3] Cuoco, A., Goldenberg, E.P. and Mark, J., "Habits of Mind: an organizing principle for mathematical curricula", Journal of Mathematical Behaviour 15 (1996): 375-402. Available at http://jwilson.coe.uga.edu/EMAT7050/Cuoco.HabitsOfMind.pdf (accessed 2 December 2021)
[4] Gauld, C.F., "The scientific attitude and science education: A critical reappraisal", Science Education 66 (1982): 109-121. Available at https://onlinelibrary.wiley.com/doi/epdf/10.1002/sce.3730660113 (accessed 2 December 2021)
[5] Calick, M. and Coll, R., "Investigating Sociascientific Issues via Scientific Habits of Mind: Development and validation of the Scientific Habits of Mind Survey"' International Journal of Science Education 34, no. 12 (2012): 1909-1930. Available at https://www.tandfonline.com/doi/full/10.1080/09500693.2012.685197 (accessed 13 November 2021)
[6] "Thinking like an engineer: Implications for the education system", Royal Academy of Engineering and the Centre for Real-World Learning (May 2014). Available at https://www.raeng.org.uk/publications/reports/thinking-like-an-engineer-implications-full-report (accessed 22 October 2021)
[7] Four main types of identity have been identified in the literature, but the context of Next Engineers requires a focus on role identity - the meaning you attach to a particular social or cultural role or the role (or character) you play when holding specific social positions in groups. You may hold various roles, but each has its own meanings and expectations that are internalized as identity.

been shown to be "central to learning in engineering and its development is a core aspect of the education and training process for engineers. Identification with engineering has been shown to assist in the recruitment of diverse students into the field and to improve student retention among all groups"[8]. It has also been shown to be a significant indicator of educational and professional persistence in multiple quantitative and qualitative studies[9].

5 Agency

Agency is what allows someone to take an active role in **shaping their future** rather than being solely influenced by their circumstances[10]. Exercising agency requires:

- a capacity for **self-efficacy** (an individual's belief in his or her capacity to execute behaviors necessary to produce specific performance attainments[11]);
- a growth mindset (a **self-perception** wherein an individual believes that their intelligence and abilities can be developed and improved[12]); and
- **intentional planning** and forethought to set a course of action and adjust it as needs be[13].

Having an awareness of engineering, an interest in pursuing an engineering career, being able to think like an engineer and identify as an engineer must culminate in agency. Next Engineers supports student agency by giving students the knowledge and skills to **identify, access, pursue**, and **persevere** on the route to becoming an engineer.

HOW TO BUILD AN ENGINEERING IDENTITY

- **Recognition**: Recognition messages from parents, teachers, instructors, and peers are important for identity formation.
- **Interest**: A student's interest in engineering plays a key role in whether students want to take on the role identity of an engineer.
- **Performance/competence**: Students' beliefs in their own performance and competence, closely related to their self-efficacy, can be a significant positive predictor in engineering persistence.

Agency

Agency is the "human capacity to influence one's functioning and the course of events by one's action."

Agency is exercised through
- Intentionality
- Forethought
- Self-reflection
- Self-regulation

— ***Albert Bandura***[b]

[8] Tallman, B., Schell, W., Sybesma, T., Kwapisz, M., Ranch, S., Hughes. B., Bozic, C. and Kotys-Scwartz, D., "How do engineering undergraduates define engineering identity?", Proceedings of the International Annual Conference of the American Society for Engineering Management, Huntsville (2019). Available at https://www.proquest.com/openview/781070295d407216efbb0c00eac48d1b/1?pq-origsite=gscholar&cbl=2037614 (accessed 16 November 2021)

[9] Goodwin, A., "The Development of a Measure of Engineering Identity", ASEE Annual Conference and Exposition (2016). Available at https://monolith.asee.org/public/conferences/64/papers/14814/view (accessed 2 December 2021)

[10] Bandura, A., "Toward a Psychology of Human Agency", Perspectives on Psychological Science 1, no. 2 (2006).

[11] Bandura, A., "Self-efficacy", In V. S. Ramachaudran (Ed.), Encyclopedia of human behavior 4 (New York: Academic Press, 1994), 71-81. Available at https://www.uky.edu/~eushe2/Bandura/Bandura1994EHB.pdf (accessed 13 November 2021)

[12] "Carol Dweck revisits the 'Growth Mindset'," Edweek, accessed 2 December 2021, https://www.edweek.org/leadership/opinion-carol-dweck-revisits-the-growth-mindset/2015/09

[13] Badura, A., "Self-efficacy Beliefs as Shapers of Children's Aspirations and Career Trajectories", Child Development 72, no. 1 (January / February 2001):187-206. Available at https://www.uky.edu/~eushe2/Bandura/Bandura2001CD.pdf (accessed 14 November 2021)

[b] "Agency", Albert Bandura, accessed 3 December 2021, https://albertbandura.com/albert-bandura-agency.html

Annex A: Engineering Habits of Mind

There are several different models and frameworks of engineering habits of mind. While there are some differences, by and large, they each put forward very similar sets of thinking dispositions. Next Engineers has adopted the model developed jointly by the Royal Academy of Engineering and the Centre for Real-World Learning[14] because it captures most of the key features of other models, is relatively straight-forward, has been validated and is paired with detailed descriptions of pedagogical methods for helping students develop each habit of mind.

The Royal Academy of Engineering is the U.K.'s national academy of engineering, whose goal is to "harness the power of engineering to build a sustainable society and an inclusive economy that works for everyone."[15] It is an active advocate for and policy developer in promoting engineering and related careers in schools throughout the U.K.

The Centre for Real-World Learning at the University of Winchester is a leading institution researching and implementing dispositional teaching (methods of instruction that develop positive learning dispositions in students likely to help them thrive in the real world) in schools and colleges.

The following provides brief descriptions of the six engineering habits of mind.

- **Systems thinking**: Engineers can see the whole system and its parts and understand how they connect and interrelate. This requires recognizing patterns and interdependencies and synthesizing and analyzing information from different sources. It also requires balancing competing priorities, criteria, and constraints.
- **Problem-finding**: The correct formulation of a problem is often essential to it being solved. Engineers, therefore, investigate problems in different contexts and clarify and verify needs to come to a full, comprehensive, and correct understanding of the problem. Engineers find problems that are worth solving. They also check and evaluate the efficacy of existing solutions.
- **Visualizing**: Engineers move between the abstract and concrete fluently and so produce practical design solutions that simplify complexity. In doing so, engineers investigate and manipulate different materials, processes, and physical spaces and translate their imaginings into physical artefacts like annotated drawings and models.

HABITS OF MIND

For fuller descriptions of each habit of mind, visit https://www habitsofmindinstitute.org/what-are-habits-of-mind/.

HOW TO DEVELOP NEW HABITS

- Constant repetition of the habitual action;
- A stable context in which to perform it; and
- The provision of an appropriate reward for completing the action.

KEY PRINCIPLES FOR DEVELOPING HABITS OF MIND

- Facilitators and learners need to fully understand the habit and recognise it when it is being used successfully.
- Facilitators need to create the climate for the habit to flourish, including rewarding it.
- Facilitators need to choose methods that facilitate the practice and transfer of the habit.
- Facilitators need to build learner engagement and commitment to the habit.

[14] "Thinking like an engineer: Implications for the education system", Royal Academy of Engineering and the Centre for Real-World Learning (May 2014). Available at https://www.raeng.org.uk/publications/reports/thinking-like-an-engineer-implications-full-report (accessed 22 October 2021)

[15] "Who we are", The Royal Academy of Engineering, accessed 14 November 2021, https://www.raeng.org.uk/about-us/who-we-are

- **Improving**: Engineers relentlessly try to make things better through experimenting, designing, sketching, guessing, conjecturing, thought experimenting, and prototyping.
- **Creative problem-solving**: Problem-solving is at the heart of the engineering process. Engineers collaboratively select and apply techniques from a wide range of traditions and disciplines to generate novel ideas. These ideas are then subject to rigorous but generous critique.
- **Adapting**: Engineers are prepared to constantly rethink, reframe, reconsider, reinterpret, review, and respond. Engineers need to be able to change their mindset. Equally, however, engineers can adopt and adapt materials and processes by changing them, combining, and recombining them in new ways.

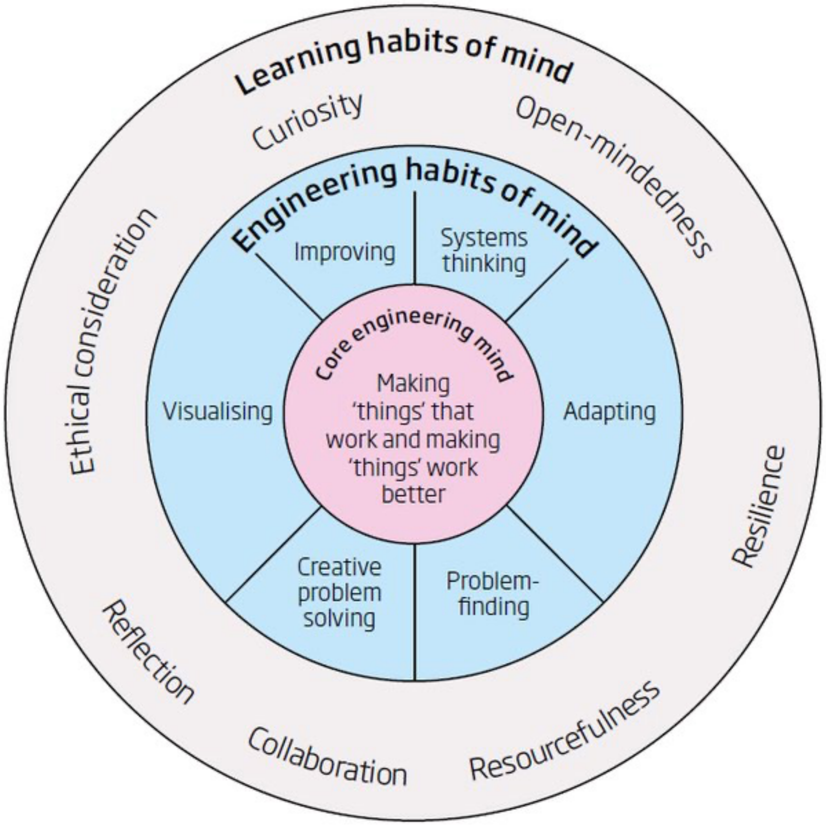

Figure 1: The Engineering Habits of Mind[16]

HOW TO DEVELOP ENGINEERING HABITS OF MIND

- Embed the engineering design process.
- Allow students to tinker (exploring through fiddling or playful experimentation).
- Provide opportunities for authentic learning with practitioners like professional engineers.
- Ask open-ended questions.
- Encourage experimentation.

[16] Image of the Engineering Habits of Mind is used under fair use. Available at https://www.raeng.org.uk/publications/reports/thinking-like-an-engineer-implications-full-report (accessed 22 October 2021)

Annex B: Self-Efficacy and Growth Mindset

Self-efficacy

Albert Bandura, professor of Psychology at Stanford University, is regarded by many as the foremost expert on human motivation. A 2002 survey ranked him as the fourth most cited psychologist of all time, behind Skinner, Freud, and Piaget.

Bandura posited that efficacy beliefs influence how people feel, think, motivate themselves, and act. Self-efficacy refers to an individual's belief in their capacity to execute behaviors necessary to produce specific performance attainments[17] and reflects confidence in the ability to exert control over one's own motivation, behavior, and social environment.

Self-efficacy affects the goals for which people strive, the amount of energy they are prepared to expend toward achieving that goal, and their likelihood of attaining particular levels of performance in these efforts. Students with high self-efficacy will work harder and try longer. They will tend to recover more quickly from setbacks and overcome greater obstacles.

Unlike many traditional psychological constructs, self-efficacy beliefs are domain and circumstance specific. One can have high self-efficacy in Mathematics but low self-efficacy in Biology.

The opposite of self-efficacy is learned helplessness. The concept, first developed by Martin Seligman and Steven Maier in 1965, describes passive pessimists who display a victim mentality and believe that they have no power over circumstances and nothing they can do will contribute to their success.

Albert Bandura described four key ways in which student self-efficacy can be developed[18]:

- **Mastery of learning experiences**: Providing students with opportunities for earned accomplishment and genuine competency. This means creating well-structured learning environments that stretch students and give them an opportunity for productive struggle and failure on the way to achievement previously thought unattainable.
- **Vicarious experiences**: Seeing or reading about 'people like me' or role models who have achieved or accomplished something through the repeated overcoming of failure and setback.

[17] Bandura, A., "Self-efficacy", in Encyclopedia of human behavior, Vol. 4, pp. 71-81, ed. V. S. Ramachaudran. (New York: Academic Press, 1994), 71-81. Available at https://www.uky.edu/~eushe2/Bandura/Bandura1994EHB.pdf (accessed 2 December 2021)

[18] Bandura, A., "Social Cognitive Theory", in Annuls of child development, Vol. 6. Six theories of child development, ed. R. Vasta (Greenwich, CT: JAI Press, 1989), 1-60. Available at https://www.uky.edu/~eushe2/Bandura/Bandura1989ACD.pdf (accessed 2 December 2021)

- **Verbal persuasion**: Providing information, guidance, and constructive feedback that boosts students' sense of control and ability and willingness to exert control.
- **Physical and emotional states**: Helping students to regulate and manage their emotions, especially negative emotions, and maintain healthy physical habits like diet, exercise, and sleep.

While people with high self-efficacy are willing to engage in tasks they feel confident in completing, they may withdraw from tasks where they currently lack confidence. This is where the development of a growth mindset becomes important for agency.

Growth Mindset

The concept of a growth mindset was first developed by Carol Dweck, also of Stanford University, and expounded in her enormously influential 2006 book Mindset: the New Psychology of Success.

A growth mindset is a belief that your capacity for intelligent thought and action is not fixed or static. It can be developed and improved. A growth mindset is not growth itself. It is the belief that growth is possible. Without a growth mindset you cannot start on the growth journey. This belief has an enormous impact on motivations and actions.

If you have a fixed mindset, you believe that your talents, abilities, and dispositions are fixed and cannot be changed. You may also believe that your talent and intelligence alone lead to success, and that effort, therefore, is not required.

Carol Dweck's research into mindset suggests that students who have adopted a fixed mindset may learn less than they could or learn more slowly. They also tend to shy away from challenges as poor performance may confirm that they are 'dumb' or indicate that they are less intelligent than they believe.[19] The result is an unwillingness to work at getting better or attributing failure to an external force.

Dweck's research also suggests that a growth mindset "creates a love of learning and a resilience that is essential for great accomplishment"[20]. Students who embrace growth mindsets—the belief that they can learn more or become smarter if they work hard and persevere—may learn more, learn it more quickly, and view challenges and failures as opportunities to improve their learning and skills.

However, two common misconceptions are the idea that hard work is all that is required for learning success and that simply understanding growth mindset and talking about it means having a growth mindset.

GROWTH MINDSET AND EFFORT

Having a growth mindset means putting the effort in. But **non-strategic** or **mis-directed** effort is unlikely to produce the desired results and can actually lead to students feeling more inept.

HOW TO DEVELOP A GROWTH MINDSET

- Change "Not everybody is good at math. You did your best" to "When you learn how to do a new kind of problem, your math brain grows."
- Change "That's OK. You're not a science person" to "Your struggle right now only means that you are not a science person yet."
- Change "Don't worry. Just keep trying" to "That feeling of this being hard is the feeling of your brain growing."

[19] "Carol Dweck revisits the 'Growth Mindset'," Edweek, accessed 2 December 2021, https://www.edweek.org/leadership/opinion-carol-dweck-revisits-the-growth-mindset/2015/09
[20] Ibid

In reality, few people have a purely growth or fixed mindset. We usually possess some mixture of the two, depending on the context. To develop your capacity to access the growth mindset, you need to accept areas where you have a fixed mindset and identify the triggers that set it off.

A summary of the key differences between a growth and fixed mindset are illustrated in figure 2.

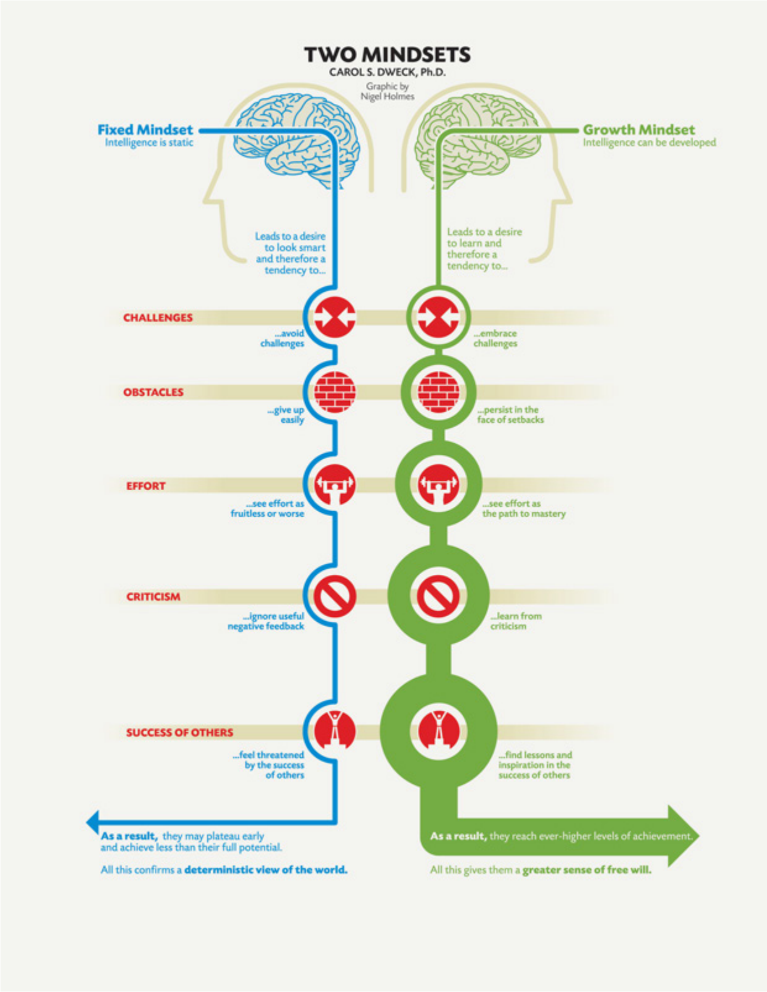

Figure 2: Two mindsets[21]

[21] Image of the Two mindsets by Carol Dweck is used under fair use. Available at https://fs.blog/carol-dweck-mindset/ (accessed 2 December 2021)