Writing Learning Objectives that Engage Future Engineers:
Hands-on & Minds-on Learning Activities

S. K. Barnes [1]
Associate Professor
James Madison University
Harrisonburg, VA USA
barnessk@jmu.edu

Keywords: elementary, engineering, education, objectives

INTRODUCTION

One of the first steps in planning engaging instruction for primary and elementary grade children is to determine the learning objectives for the young learners. From clearly developed objectives, educators can select appropriate materials and activities to stimulate student interest, and to develop assessments to document the impact on student learning. Engaging students in interesting engineering learning experiences early is critical for motivating them to pursue engineering careers and to eventually serve as mentors to other future engineers. The impact data are critical for providing evidence of teacher effectiveness and of student achievement, information that can serve to motivate teachers and students to continue their engineering education endeavours.

Two types of learning objectives will be discussed in this paper. The first type includes objectives for student skill development. These objectives are typically skills that are directly observable (e.g., the student will build, the student will create). The second type is what one can refer to as thinking objectives and are more hands-on/ minds-on and less easily observed (e.g., the student will compare, the student will consider). For each kind of objective, teachers need to develop observable behaviour indicators. These indicators can include language, such as specific engineering or mathematical vocabulary that they expect students to use while engaged with particular materials, or the indicators may be behaviours that teachers expect to see, such as collaborating to accomplish a task or sharing materials. Teachers use assessment in primary and elementary and of teacher effectiveness. Assessments used during children's engineering activities are unlike assessments in

[1] Corresponding author
S. K. Barnes
barnessk@jmu.edu

a specific content area where the teacher is grade classrooms to provide evidence of student mastery of a particular objective, an indication of student learning looking for the student to demonstrate mastery in a particular math skill such as one-to-one correspondence. Children's engineering activities, by their very nature, integrate many skills and learning objectives across the disciplines. The objectives and outcomes of primary and elementary engineering education are not always clearly mapped to one of the four STEM disciplines, science, technology, engineering, and math, but are often cross-curricular in nature, addressing content, practices, and skills from not only the STEM disciplines, but also from others such as language arts and social studies.

Curriculum planners and teachers using standards from the various disciplines are presented with rich opportunities for observing student achievement during classroom engineering activities, but careful planning is needed to efficiently collect evidence in multiple domains simultaneously. Examination of crosscutting concepts [1] reveals that ideas and practices of technology (system models, mechanisms and prediction) and engineering (structure and function), are integral to engaging and meaningful primary and elementary education experiences. Decisions on which objectives to assess should be based not only on standards, but also on data that teachers have from their own ongoing formal and informal assessment results that provide information regarding what their students are ready to learn and what students are interested in learning.

This paper describes a process of developing meaningful, hands-on and minds-on objectives that will stimulate student interest in engineering, and support planning, instruction, and assessment of the learning experience in the primary and elementary classroom. Developmental characteristics of children that impact the appropriateness of engineering activities are briefly discussed. Subsequent sections describe the processes of determining and selecting learning outcomes, given the interest and readiness of children for engineering activities, writing objectives, engaging young learners, and planning approaches to document student achievement.

1 CHARACTERISTICS OF YOUNG CHILDREN AS ENGINEERS

1.1 Development

When planning engineering experiences for children under twelve years of age, teachers should bear in mind that children vary in their development. Children mature at different rates overall and within the different developmental domains. For example, it is not unusual for a six year old child to display the cognitive developmental characteristics of a child a year or two older, reading chapter books and solving complicated puzzles, while still struggling to complete fine motor tasks typically mastered by younger children, such as writing his name on lined paper and using scissors to cut a curved line. Still, it is helpful to consider the characteristics of typically developing children when planning engineering activities for a class and then to intentionally differentiate instruction to meet the developmental needs of some individuals.

The constructivist theory of cognitive development, commonly attributed to Jean Piaget [2], gives a picture of young children as preoperational. In other words, they are active learners who construct their understanding of the world through active engagement using their senses. Relying on auditory and visual perception, they need something they can see and touch in order to understand it. Many older elementary children are able to think about innovations that they have never personally experienced, but hands-on experience is still important for their understanding. Another trait that young children exhibit is centrism, the characteristic of giving attention to only one idea at a time. The limit on children's ability to process or synthesize complex information makes it difficult for them to make high-level evaluations when engineering tasks have many constraints or variables to consider.

Language development is another important consideration. Typically, young children have smaller receptive and expressive vocabularies than older children. Similarly, dexterity with eye-hand coordination improves as children mature. The narrower range of control of their fingers translates into restricted use of some design tools and materials. These still emerging language and fine motor skills will impact children's ability to implement, record, and share their design ideas, to ask clarifying questions, and to request specific help or feedback on engineering problems. The ability to communicate ideas, verbally and graphically, are key for successful implementation of engineering learning activities.

1.2 Readiness

The cognitive and physical developmental levels of children contribute to their overall readiness for engineering tasks. Readiness refers to the degree to which the students' skills and understandings are matched to the task. Readiness is also impacted by children's social development and by their previous experiences in engineering tasks. While engineering activities can be done independently, ideally students work in groups, consider the perspective of others, and share materials and space. Some children have been practicing these social (soft) skills with siblings or peers at home and nursery school since they were toddlers, while others may have very limited experience working and playing with other children. The ideas of turn-taking and negotiation can be difficult for these children. They benefit from some coaching on how to work as members of an engineering team.

Experienced young engineers have been tinkering with materials, tools, and supplies found at home and in other settings since before they can remember, while others will need more support in their initial use of engineering tools and processes. Scaffolding provides the help that students need to succeed in challenging work that may be a bit beyond their initial comfort zone. Strategies for scaffolding include modelling, assigning partners who have more experience, providing directions that include more detail and graphics that help students interpret the meaning of the text, and allowing more time to complete tasks. Considering readiness is important because when learning activities are too simple, children can get bored, and when tasks are too difficult, the students can become frustrated. Either scenario may cause students to disengage from the engineering activities, and engagement is key to creating learning experiences that are hands-on and minds-on, extending children's understanding of the engineering processes as well as the underlying principles.

1.3 Interest

Perhaps one of the most important aspects of engaging students in engineering is the level of interest the children have in the learning activity. In this case, interest refers to the level of curiosity a student has in the project. When teachers help students to see the connections between their own ideas and interests and the engineering activities and then invite students to use ideas that are familiar and interesting to them to help master new engineering challenges, students are more likely to be engaged in hands-on and minds-on learning. Children who see the connections between concepts are able to make more meaning from their experiences inside and outside of the classroom. Enthusiasm for learning fuels interest as well. Teachers who enthusiastically introduce new ideas and topics have opportunities to expand their students' current interests to new areas. Interested students are more motivated to participate, to learn, and eventually to select engineering subjects and careers.

2 ENGINEERING LEARNING OBJECTIVES APPROPRIATE FOR CHILDREN

2.1 Engaging young engineers in meaningful activities

To stimulate student interest in engineering subjects and careers, some primary and elementary schools are providing design-based professional development to teachers who are typically prepared to teach math and science, but who have had little formal technology or engineering design experiences in their teacher preparation programs. Adopted curricula typically provide teachers with lesson plans that include a list of materials and step-by-step procedures for implementing an activity. The appropriateness of these activities should be carefully examined before implementation. Appropriateness is determined by doing a task analysis, comparing what the students would be required to do to participate in the engineering activity with the characteristics of young students described in the previous section. Teachers need to use their own judgement to determine if these published activities will be meaningful and enjoyable for their particular students. These judgements should be based on assessment data.

Assessment data can be formal or informal. Formal assessment data are typically universally collected by schools, and include reading inventories or standardized diagnostic tests. These assessments can provide some information that can help teachers to determine if students have requisite skills or if they have some misconceptions that need to be addressed. For example, a reading inventory may determine the likelihood that a student would be able to follow directions on an engineering log included in a grade level curriculum. These data are of limited value throughout the school year because student performance levels typically change as students mature and engineering activities are typically implemented with peer support. A teacher-created interest survey is an example of an informal diagnostic assessment that may be very useful to teachers when selecting or creating learning activities. Other informal assessments, such as teacher observations of student choices of books or of student passions for topics, can help teachers determine if an activity is likely to be successful with a particular group of children.

2.2 Appropriate learning objectives

When engineering activities are considered appropriate for students, that is, suited to their readiness and their interests, teachers still need to determine if the activities are worthwhile endeavours. These determinations are made by evaluating how well the activity meets the objective of extending student learning. To be worthwhile, students should be supported to master new skills through hands-on learning or to construct understandings beyond what they already know through minds-on learning. Students should be presented with opportunities to collaborate and to test their propositions about their world as they engage in purposeful tasks related to real world problems. When done well, hands-on, engaging activities can help students construct deeper understanding of scientific concepts. Even primary grade children under age five are able to learn about important physics concepts of acceleration and friction when they design and build ramps in the block area of early childhood classrooms. Teachers need to be intentional when planning learning experiences for their students, considering the learning objectives. They need to be thoughtful about exactly what students will be doing, thus developing skills through hands-on activities, and about what students will be learning, hence developing understanding through minds-on engagement. The goal should be to optimize opportunities for both kinds of learning outcomes by carefully articulating the learning objectives.

2.3 Writing hands-on and minds-on objectives

Writing hands-on and minds-on objectives is part of a larger process, a cycle of being responsive to students. This process starts with determining students' readiness and interests and is followed by setting clearly defined hands-on and minds-on objectives, providing opportunities for students to learn and demonstrate growth, selecting a method to collect evidence of that learning and development, analysing those data in a meaningful context, and using the data to inform subsequent instruction. Setting specific objectives determines the knowledge and skills that should be assessed as well as how to facilitate the opportunities for the students to demonstrate that knowledge and skill and how to measure student growth and development.

After considering the results from the diagnostic assessments used to determine student readiness and interests, teachers should turn to core ideas and concepts of engineering embedded in the related disciplines of science, mathematics, and technology. Content standards to consider include those developed by local school systems, national guidelines, and professional associations. The Next Generation Science Standards [3] were used to develop the Engineering is Elementary® (EiE®) curriculum [4]. The EiE® curriculum is the foundation for the ENGINEER [5] curriculum project now used in nine European countries and Israel. The International Society for Design and Development in Education (ISDDE) awarded their annual prize for excellent curriculum design to the team that developed EiE®.

National content standards for K–12 engineering education have not been developed in the United States. Standards-like documents for precollege engineering education have be developed by other nations, including England, Wales, France, and Germany, but concepts in engineering are rather implicit in the primary and elementary level standards [6]. Given that there is such a close relationship between engineering and the disciplines of science, mathematics, and technology, there is often overlap from one discipline to another, particularly with engineering and science. Standards in these other content areas provide a rich resource for aligning engaging engineering learning experiences with appropriate content standards. Consider, for example, the topics of engineering design and scientific inquiry. These two topics are very similar in that they both use models of complex phenomena to understand problems and both subjects use mathematics to analyse and aggregate data. Examination of the crosscutting concepts from the National Academy of Science *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* released by the National Research Council [7] reveals that crosscutting concepts address ideas and practices of technology (system models, mechanisms and prediction), engineering (structure and function), and mathematics (patterns, scale, proportion, and quantity) as well as the science concepts. Another overlap is easily seen in the area of language arts and engineering wherein both disciplines require students to communicate ideas and results to others. When reviewing standards for the disciplines to determine what content should be taught, teachers should not be bound by grade level expectations. Students actively engaged in meaningful and interesting activities can push themselves beyond the standard level of performance expected for their grade or age group.

After determining what should be taught, teachers turn their attention to how they can provide students opportunities to learn and to demonstrate that learning. Engineering education materials and curricula have been developed by professional engineering associations, non-formal education entities such as parks and museums, and formal education agencies such as universities and school districts. Teachers can get lesson plan ideas and other resources such as games and software while attending their professional development conferences, reading books and journals, and visiting websites. With so many choices, and many teachers lacking deep understanding of engineering content, it may be a challenge for classroom teachers to select materials.

Is it during this step that teachers need to think carefully about just how they will know their students have mastered a skill or developed an understanding of the concepts that have been identified as the hands-on and minds-on learning objectives. Teachers need to develop an explicit set of behaviour indicators. In other words, they need to clearly articulate the behaviours they expect to see if the objectives of the engineering activity are met. These indicators can include language, such as specific scientific or mathematical vocabulary, that they expect students to use while engaged with particular materials, or behaviours that teachers expect to see, such as sharing space and materials during collaborative assignments. Table 1 provides examples of hands-on and minds-on learning objectives for young children. When teachers have decided what products or behaviours they need to see in order to know that students have met the learning objectives, then selecting the activities is a more straightforward process of determining which tasks and challenges will provide students multiple opportunities to practice and to demonstrate those behaviours.

3 ASSESSING STUDENT LEARNING

3.1 Purposes

There are three main purposes for assessment. Diagnostic assessment, discussed earlier, provides information about what students already know, what they are ready to learn, and what they are interested in learning. Formative assessments guide the ongoing interactions that teachers have with students and are used to plan subsequent instruction. When teachers ask students to explain why they tried a particular approach to solve an engineering problem, they are using formative assessment in order to understand the students' intentions. This is one way the teacher can accurately assess if the students are making effective decisions. Asking questions is the primary way that teachers check for understanding. Summative assessment data are typically used to document change over time. These data are useful when teachers need to describe how students' thinking and skills have developed and improved. Summative data are also used for setting goals and for evaluating teacher or program effectiveness.

3.2 Approaches

The remainder of this paper addresses the critical question of what teachers need to know and to do in order to capture meaningful and useful data to measure student hands-on and minds-on learning and to inform professional practice in the primary and elementary classrooms that are using engineering activities. Ongoing formative assessment during learning activities will alert teachers when students are not meeting expected goals and when they are ready for new challenges. Sometimes an adopted engineering curriculum will include templates or worksheets for students complete during the activities, providing teachers with a way to collect evidence of student progress. Teachers of younger children typically use observational data gathered while children are engaged in activities in naturalistic classroom settings.

Checklist and tally sheets are easy for teachers to develop and use after they have identified the specific behaviours they expect to see if their objectives are met. These approaches often provide information on how well students are performing with the support of their peers, so teachers will need to use these data with other observations or assessments in order to get a clearer picture of what individual children can do on their own. Assessment of hands-on learning is often accomplished through the evaluation of products or the rating of the performances of some technical procedure, such as using a tool or instrument to complete a task. Minds-on learning assessment data can be collected by an observer, such as the teacher, or by the students themselves. While traditional notebooks can provide teachers with some insight into what students were thinking when they were working, more powerful data can be collected when students share their thoughts with others who can give them more immediate feedback. Blog posts and Google docs are free and efficient ways for students to share their individual contributions to team projects and to provide teachers with a glimpse of what individual students were thinking as they solved problems. The time and date stamp on most digital technologies is helpful for documenting student growth over time.

Sometimes a more precise measurement of to what degree a student meets the hands-on and minds-on objectives is needed. In these cases, a rubric with performance indicators can be helpful. *Table 1* is an example of how a primary grade teacher might write hands-on and minds-on learning objectives with performance indicators. Using a prepared list is helpful to focus the teacher's attention on particular behaviours during observations.

Table 1. Hands-on and Minds-on Objectives and Behaviour Indicators

<table>
<tr><th>Type</th><th>Objective</th><th>Performance Indicators</th></tr>
<tr><td>Hands-on</td><td>The student will construct a ramp that allows the marble to roll beyond the initial pathway.</td><td rowspan="2">Behaviour indicators:
Level 1. Adds a block under the ramp, test with marble.

Level 2. Adds blocks under ramp and tests with marble. Removes blocks and re-tests.

Notes distance of roll increased with blocks added under the ramp.

Notes distance of roll increases with the number of blocks added under the ramp.

Continues to add more blocks and retests. Does not remove blocks.

Language indicators:
Adding more blocks makes it go farther, a higher ramp works better, steeper ramps make the marble roll more</td></tr>
<tr><td>Minds-on</td><td>The student will understand that the degree of the ramp's incline impacts the distance that the marble will roll on the pathway.</td></tr>
</table>

REFERENCES

[1] National Academy of Sciences (NAS). (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. National Academies Press, Washington, DC.

[2] Charlesworth, R., (2014), Understanding child development, Cengage, Belmont, CA, USA, pp. 12-18.

[3] Next Generation Science Standards, (2013), Achieve, Washington DC.

[4] Engineering is Elementary. http://www.eie.org/blog/eie-blog-excellent-design-0

[5] ENGINEER (2013), Brochure retrieved from http://www.engineer-project.eu/wpcontent/uploads/2013/05/Engineer-brochure.pdf

[6] DeVries, M.J., (2009). Report for NAE on non-U.S. Standards for Pre-university Engineering Education. Paper presented at the NAE Workshop on Standards for K–12 Engineering Education, Washington, D.C.

[7] Committee on K-12 Engineering Education. (2009). In L. Katehi, G. Pearson, & M. Feder (Eds.), Engineering in K-12 education. National Academy of Engineering and National Research Council, Washington DC.