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13 Approaches to Student Evaluation in Invention Pedagogy

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Rationale behind Evaluation

The concept of evaluation refers to the actions which are supportive of the learning process and the actions which are aimed at determining the amount and quality of the learning outcome (Black & Wiliam, 2009). Both types of evaluation are related to the aims of the invention project. When an evaluation action makes a judgment related to the achieving of the aims of an invention project or grade of the performance of a student or a small group of students, the type of evaluation is summative (Wiliam, 2000). In turn, while supporting the invention project or appraising students within an ongoing process, the type of evaluation is formative. These two main types of evaluation require individual or collective interpretation of the learning aims as well as evidence, which is used as the starting point in evaluation.

Evaluation of the invention project might be challenging because the aims of the project are typically set holistically. First, the project supports students in learning core ideas in the domain through engaging them in scientific and engineering practices, collaboration, and constructing of an educational artifact (see for example Chapter 2 of this book). Learning the scientific and engineering practices or skills needed to complete these practices are also aims of the invention project. These practices are practices that are similar to experts in the field, such as asking questions, defining problems, planning and carrying out investigations, analyzing and interpreting data, developing and using models, and communicating information (Krajcik & Czerniak, 2013). An artifact, here the invention, is an object created by students during an invention project.

Second, there are aims related to the characteristics of an artifact. To be considered as an artifact, it needs to be lasting, durable, public, and materially present (Frederik et al., 2011). Moreover, aesthetic aims, such as exceptionality and diversity, ethical aims, and aims related to sustainability, are often emphasized as aims for the artifact.

An invention project is also an environment for the learning of transversal competencies also called key competencies, generic competencies, or 21st-century competencies, such as creative and critical thinking skills, collaboration, and problem-solving skills, skills needed in the use of various tools, such as digital and manual tools (Voogt & Roblin, 2012). Therefore, aims related to the transversal

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competencies in an invention project form the third group of aims, which could be evaluated as a part of the project (Pepper, 2011). However, the development of various skills and competencies through invention or design projects does not easily reach full potential. For example, aims related to the transversal competencies are often not shared with the students (Scott & Yates, 2002). Therefore, self-evaluation and peer evaluation that move learners forward do not focus enough to the learning of transversal competencies.

In an evaluation action of an invention project, the focus is always on both the quality of the learning process (the formative type of evaluation) and the learning outcome (the summative type of evaluation) with a focus on improving students' invention process and outcomes. Therefore, both the teacher and the students use evaluation data to develop teaching and learning, and consequently, the evaluation is called enhancement-led evaluation (Atjonen, 2015; Patton, 2011). Consequently, it is important to support students in using evaluation feedback in the development of their learning process and learning outcome. This type of orientation to the evaluation is emphasized in Finnish education policy and practices and is recognized as an orientation to evaluation in this book because the authors are from Finland. In general, in Finnish compulsory school education, student assessment is the responsibility of teachers who have pedagogical autonomy in the matter, although principles of student assessment and assessment targets are defined in the national core curriculum. Standardized testing has no role in Finnish compulsory education; instead, students are encouraged to design and assess their own learning (OECD, 2020).

A quality learning process promotes students' learning and depends on cognitive activation, supportive climate, and classroom management (Hattie, 2009). The quality of the outcome of the learning process refers to how well the competencies can be used in new situations, such as in problem-solving or in new invention projects (Dixson & Worrell, 2016). The evaluation provides students and the teacher with feedback. There are several other aims of evaluation, such as making the learning process and the learning outcome transparent. The evaluation actions are always based on the verified evidence and graded according to the criteria. The criteria come from the general part of the curriculum, such as the description of transversal competencies and from the subject-specific part, such as the description of engineering and design practices.

The evaluation and the feedback affect how the students learn or work during the invention projects and get excited by the inventing (Weeden et al., 2002). Evaluation with encouragement supports a student's self-concept as an inventor. This type of encouragement and constructive feedback is supportive in the development of students' self-efficacy, in other words, their belief in their capacity to execute behaviors necessary to use their creativity and invention process (Bandura, 1997). Self-efficacy reflects confidence in the ability to exert control over one's own motivation, behavior, and social environment. It influences confidence in how the invention project proceeds and results in the invention which is pleasing to at least its inventors in its newness. Moreover, an invention project has many features known to improve growth or maker mindset (Nadelson, 2021). Therefore, the evaluation actions should indeed be constructive and encouraging during the learning of invention projects: students need to understand the feedback and, according to that, direct their learning and working in the desired direction. The feedback is directed and connected to each student's actions and outputs. The students are directed simultaneously to interpret feedback so that it will be easier for them to change their own way of operating.

Making Evaluation Relevant

The relevance of evaluation depends on a range of characteristics, such as validity, reliability, and objectivity. According to the validity characteristics, the evaluation should focus on the knowledge and skills or competencies that are aimed at learning within the invention project. The evaluation should focus on essential and relevant issues, described in the curriculum as aims for learning. Thus, the starting point for the evaluation should be the aims of the curriculum or the aims emphasized in the invention project.

The validity also includes transparency. The evaluation should be open and transparent, and the participants must know the aims of the invention project and the evaluation practices. Therefore, it is important to pay attention to the aims of the project, including aims for learning transversal competencies, and the expected outcomes of the project at the beginning of the invention project: students and teachers should share the same aims. After sharing the aims, evaluation practices to be used should be agreed upon at the beginning of the invention project. In practice, the students should be invited to be involved in the planning of the invention project and planning its evaluation. It is also important to go through the evaluation criteria with the students' parents. This is because the invention project is different from traditional teaching and learning, and it might be difficult for parents to comprehend all the aims and how they are planned to be achieved during the project. For example, parents should understand that learning to formulate problems is one of the aims in invention pedagogy, and the learning task or design problem is not clear in the beginning of a project.

Validity is also important in the context of enhancement-led evaluation. Enhancement-led evaluation aims to help students to improve their learning process and performance within the invention projects. Therefore, the formative and summative evaluation and the feedback must support the development of the learning process and working in the long run also.

The demand for the reliability of the evaluation includes the fact that the tools of the evaluation do not contain random errors and that every student is given feedback and support according to their needs and process and product are evaluated according to the agreed criteria in the same way. The objectivity of the evaluation includes the fact that the effect of the subjective factors, values, and preconceptions have been removed.

Teacher's Role and Evaluation Tools in an Invention Project

The evaluation gives the teacher's feedback on the success of the supervision in an invention project and on the progress of the project. The evaluation also further directs the development of instruction and supervision practices. The teacher's supervision is multilevel during the project: the operation is directed at the level of an individual, small groups, and the whole group. In the case of a group, the evaluation information will be interpreted by the group members at an individual level.

The teacher can influence the internal division of labor of groups and how this division of labor is realized: the negotiation of the academic and cooperative aims of the groups, roles of the group members, and individual responsibilities. In the evaluation, the teacher considers how the needs of the different students have influenced the personalization of the objectives, process, and outcomes of the project (Jahnukainen, 2011) and the level of support of the different students. This means that the variation in the objectives, invention project, and expected outcome, are taken into account in the evaluation of different students. Therefore, it is central to take the special needs of individual students into consideration already at the beginning of the invention project.

The teacher examines the invention project as a whole and at the same time estimates their own operation. To be able to do a comprehensive evaluation, the teacher needs other tools for perceiving the various groups and individual student invention projects. The invention project consists of many levels of operations, and it is challenging to keep them all in mind and sometimes because of the long-term nature of the project, even impossible. Therefore, other visual evaluation tools such as tables and color codes help a teacher to control the whole project and its evaluation and to facilitate the follow-up. The tools help the teacher to divide the process into shorter periods. The teacher strengthens their own development by anticipating their successes and by thinking what needs to be done better next time.

The teachers do not necessarily have experience with the evaluation criteria and evaluation of long-term projects, so the teachers often face a new data acquisition process and information analysis. The traditional ways of evaluation could be modified to each specific situation, but usually, they should be modified to the group in question in addition to the control of the students' actions.

Evaluation Types and Methods

Evaluation and learning are strongly connected when the diagnostic and formative purposes of evaluation are highlighted. The evaluation methods described in the following sections form the evaluation in an invention project. Invention is not a linear process, so diagnostic and formative evaluation are emphasized during the process. The portfolio evaluation, presented later, includes all three evaluation methods.

Diagnostic Evaluation: Evaluation before Learning

The aim of diagnostic, declarative or planning evaluation is to find the skills and perceptions needed by the students in the invention project. Tools for diagnostic evaluation include various tests, teacher questioning, and observations (Leighton

& Gierl, 2007). The questions posed by the teacher direct the student to look at the invention project from a particular perspective. The student's response tells the teacher what the student thinks about the topic. For example, a review of the "if-then" structure used in coding can begin with the question:

> What different smart processes have you recognized at home? Or in more detail, what automatic processes are typical to house heating or cooking with an electric plate? (An answer: the electric plate heats until the selected temperature is achieved and then the heating stops). Which everyday objects could benefit from smart processes and what kind?

Or: "Tell us about a situation in everyday life in which you have previously acted to decide what to do: if you do—then you do it—otherwise…"

While they are being questioned, the students should be given sufficient time to think about the question. Therefore, it is good sometimes to ask questions on a whiteboard or via an online environment. Students may be asked to discuss the questions in small groups, write or draw an answer, and compare answers between the groups. Answers can also be presented by taking pictures of the environment or during a school trip. Answers, pictures, or thoughts should be discussed constructively—not through negative evaluations.

A test, Kahoot,[1] or Socrative[2] activity could also be used to map the students' conceptions or skills: Which of the processes include the "if-then" structure: (a) listening to music, (b) heating water in an electric kettle, (c) writing a document. Teachers can ask questions that they know to be critical for the success of the students' work: "How are the results reported?", "What keywords did you think you should use in a search?" In a similar way, it is possible to map the way in which the students have understood the aims of the invention project: "What and how we are evaluating in the invention project?", "What sensors/electrical equipment do you think you will need in your project?" The questions help students think about aims of the project.

In the context of diagnostic evaluation, students often respond in an unexpected way because the topic has not yet been studied, and they do not know the concepts or skills needed in the project. Therefore, it is particularly important to provide encouraging feedback to students. After the student's answer, a teacher naturally continues with a follow-up question. If the answer is vague, the student may be given an opportunity to modify the answer. The teacher can repeat or slightly modify the student's answer, for example, by asking, "Do you mean that…" (repeating the answer in your own words), "You bring up perspectives A and B, would there be other perspectives?", "What do you think about C?" The types of feedback given by a teacher can be grouped as follows:

- Encouraging feedback: emphasizing competence
- Evaluative feedback: highlight positive perspectives and ask to look at it from another perspective, for example
- Guiding feedback: how the objectives should be considered in the future

Formative Evaluation: Evaluation during Learning

Formative evaluation was used during the invention project to support the student's invention project and learning. Moreover, peers could be active in giving feedback during the process, such as during the communication sessions. Therefore, it is important to ask students to communicate the phase of the invention project to other students and the teacher after the students have formulated the problem or challenge of the invention project, generated ideas, and selected the most appropriate ideas related to the invention, and after the prototyping.

The feedback provided by the teacher during the invention project, as well as the self-evaluations and peer evaluations help the students to understand their learning and invention project and to identify the development of their skills and knowledge and areas where competencies are not yet sufficient. The students learn to correct their mistakes and develop their working so that the goals set for the project and learning can be achieved. The feedback could be given orally, adding comments to the portfolio or learning diary or with structured forms. Therefore, it is important that at different stages of the invention project, students communicate to the teacher and to each other about the stage and results of the project.

Formative evaluation guides regulate the student's working and learning toward the aims set for the invention project. Its primary function is to help students to discover what they know and how, or are able to do, and what still needs to be learned and in what way (Webb & Jones, 2009). Formative evaluation helps the teacher to focus his or her support and supervision on issues that students do not yet know. Formative evaluation can also support the student's feeling of competence. The need for competence is one of the key basic psychological needs or motivating factors in learning.

Summative Evaluation: Evaluation after Learning

Making the achievement of the aims and learning visible is the evaluation of knowledge and skills which have been learned or summative evaluation. Evaluation of knowledge and skills are based on verified evidence of how well and to what extent the student has achieved the aims set for the invention project (Doran & Tamir, 2002)

The knowledge and skills achieved in an invention project are rarely evaluated by a traditional test. Summative evaluation is done more often by an observation form, a learning diary, a portfolio, or based on a screening test. Documents, reports, blogs, or videos written or produced by the students could also be evaluated. Summative evaluation could be implemented through the evaluation of the invention created in the invention project. A specific evaluation sheet, constructed based on the aims of the project, could be used in the evaluation of the invention. It is common to evaluate the invention base on its usability or functionality and based on aesthetic and ethical criteria.

Self-Evaluation and Peer-Evaluation Methods

Through self-evaluation, the students find out what they have learned, compare their learning to the set aims, and strive to find out what should still be learned.

They can also recall how they have worked during the invention project and how they could work more effectively next time. Self-evaluation is thus like formative evaluation and intended to support the invention project and learning. It helps students to become responsible for their project and their learning. Self-evaluation also supports the development of metacognitive skills, self-confidence, and self-image. In addition to learning, the use of a self-evaluation method develops readiness for further studies and adult life (Andrade, 2019).

It is known that self-evaluation is challenging for students. Therefore, students' self-evaluation should be supported by teacher-led discussion, teacher questioning, or assigning a task. The discussion can be started by asking the student to share their experiences of the project in general. Next, the student could be asked to look at their own activity during the project and to think about what kind of problems they had. Finally, the students could be encouraged to analyze how they can develop their working and learning. The students' self-evaluation could be supported, for example, with a question, "What was the most interesting/surprising/charming thing about the invention project?" This question guides students to evaluate what they have learned during the project. Other examples of questions that guide the self-evaluation process include: "List the three most important things you learned during the project," and "What else would you have liked to learn?" Students can be asked to write the answers on a common page of the project or on other digital platforms. After writing, they can be instructed to compare their responses and discuss each other's experiences. It is important to guide students to evaluate their invention project asking the students, for example, "How have you succeeded in your group in collaboration, idea generation, prototyping, and communication?" "How can you improve your working during an invention project?"

The forms could be used for guiding the self-evaluation. There may be fixed and open-ended questions on the form (see Table 13.1).

The group can also self-evaluate its own activities using other forms or relying on a discussion. As the group evaluates its own activities, group members become aware of how each group member and the group as a whole has worked. In peer review, a student evaluates working or innovation of another student or a group. In

Table 13.1 Example of self-evaluation form of students' activities

What can I do? *(1 = I need exercise, 2 = moderately, 3 = well)*			
1. I am able to search for information related to the invention project.	1	2	3
2. I am able to generate ideas.	1	2	3
3. I am able to evaluate ideas.	1	2	3
4. I am able to make a prototype and test its operation.	1	2	3
5. I am able to work in a group.	1	2	3
6. I am able to communicate during the invention project.	1	2	3
7. I am able to evaluate an invention project.	1	2	3
8. I am able to evaluate an invention.	1	2	3
What was most interesting related to the invention project?			
What else would you like to learn about the invention project?			

this case, it is important to encourage students to be positive in the evaluation and to bring up a number of perspectives. Any criticism presented should be done so constructively. For example, a question about how the robot could be made to work more smoothly could be asked (Brown et al., 2021).

Several views or aspects of evaluation are highlighted while evaluating the invention project. Divergent views are discussed and recognized in such a way that all aims for the invention project are evaluated or the invention project and product are evaluated from different perspectives. These perspectives could be found among the aims of the project, such as the external presentation of the work itself, the layout of the poster or presentation slide, the use of colors, the interest of the work, and the meaningfulness of the results.

ePortfolio—a Method for Knowledge Building, Interaction, and Evaluation

The digital portfolio, a briefcase or a folder, refers to the collection of the displays of student assignments, descriptions of the learning process, and outcomes within an invention project. The display discloses the student's diverse abilities and the reached competence levels depending on the portfolio assignment type: the open assignment type reveals more detailed and unexpected information than the ready-to-fill-in type (Kimball, 2005; Parker et al., 2012). The content of the portfolio, collected documents, consist of the process descriptions, the choices available, and the self-evaluations/the group evaluations and describe success and recognized challenges and objectives for further projects (see Figure 13.1).

Alongside the authentic documentation, the portfolio consists of two more basic elements: reflection and collaboration (Zubizarreta, 2006). (See Figure 13.2). The portfolio develops in the portfolio process from a container to a reflective report and even to a dialog (Kimbell, 2012). The content of the portfolio diversifies as the unexperienced student becomes accustomed to the method and the simplest documenting is transformed into a more diverse holistic or even abstract narration (see also Saarinen, 2021). The collected materials can be processed, reflected, immediately and/or later at an appropriate time.

In turn, the collaboration can be a multifaceted act. It can mean control or communication (of a teacher/with a teacher), producing contents (with peers), or the division of the learning in the first place. When working with the portfolio method, the learner's action develops or is transformed into a critical thinker who has "a dialog" of their own learning by themselves. The highest manifold content relies on a well-developed ability to reflect comprehensively and on student-led freedom to implement activities (Saarinen, 2021). This development or transformation also strengthens the experience of the ownership of the portfolio, which engages the learner to put more effort into their own learning and to make it more meaningful (Kimball, 2005).

The portfolio can contain a range of types of assessment: It can be shared online with the teacher when the process feedback is direct and formative by nature. If the portfolio is shared with peers, the peer feedback can be directed toward content or criteria, and due to its formative nature, it also supports the process. Finally, the contents of the portfolio comprise the material for summative assessment purposes.

Figure 13.1 An extract of ePortfolio in an invention project: Everyday Assistive (Arjen apu) (sixth grade). A burglar alarm that reacts to movement and protects your property and works as a mirror.

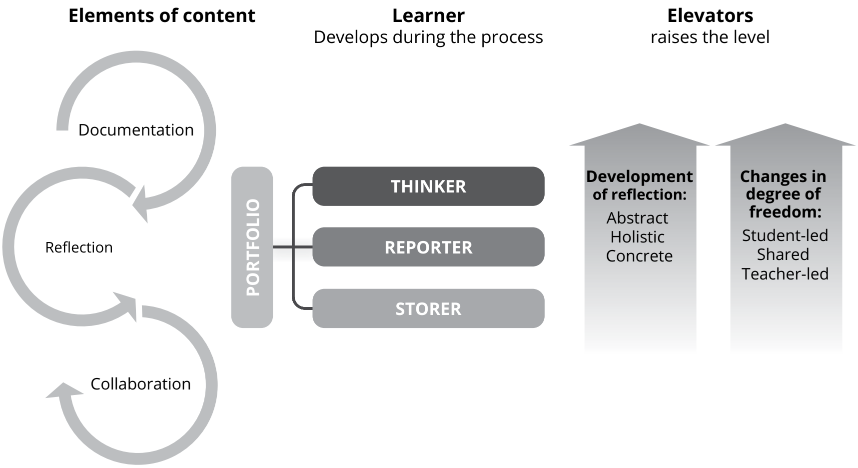

Figure 13.2 The elements of ePortfolio process and the development levels.

(modified from Saarinen, 2021).

One principle of the portfolio evaluation is that the working and the progress of it, the best achievements, and failures and coping with them are stored. One's own development is examined and with the help of the documentation, reflected either to construct a statement or the deepest level of reflective thinking (Kimball, 2005). Then also the mistakes and failures are seen but not emphasized in the same way as for example in the traditional evaluation which is based on the use of summative tests. On the other hand, the examination of mistakes and their corrections show versatile skills and abilities, and therefore it is desirable for the portfolio documentation to contain errors and mistakes. The portfolio evaluation is an attempt to strengthen learning to learn and self-direction, as well as to develop self-esteem.

Discussion

Both, formative and summative evaluation are needed in an invention project, and they can be realized through self- and peer-assessment practices. Both types of evaluation are carried out according to the holistic aims of an invention project. Formative evaluation supports the invention project and students learning during the process. Summative evaluation summarizes the student's invention project and learning outcomes. Therefore, it is more than grading, and a single grade might not be enough for summarizing. In this chapter, alternative evaluation tools, such as self-assessment evaluation, a list of evaluation dimensions, and a collecting ePortfolio method have been introduced. The ePortfolio method enables both the short- and long-term tracking of learning activities and thus gathers the evidence for assessing the process and finally assesses summatively the reached level. The ePortfolio can contain along with self-/group-interpretation views from peers and feedback from the teacher. The collected evidence becomes material for evaluation and gives a broader and authentic picture of the skills and competencies that have been achieved. Also, the transversal competencies, demanding to verify, can be more conveniently traced through the authentic evidence in ePortfolio.

However, the invention project and nonlinear learning model demand new ways of applying evaluation. Evaluation should support the creation of the student's wide-ranging creative competencies and capabilities. These open-ended problems with complex nature settings in invention projects need to be assessed with improvisation and the evaluation accomplished in a way that facilitates the process, like the ePortfolio method. Evaluation should be seen as an ongoing process with several iterations, a co-creation with learners, and as a learning event itself, not a vanishing point.

Notes

1 https://kahoot.com/
2 https://www.socrative.com/

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