Assessment of the CDIO Syllabus learning outcomes: from theory to practice

Mikhail Minin, Anastasia Kriushova, Elena Muratova
Department of Engineering Pedagogic
Tomsk Polytechnic University
Tomsk, Russian Federation
kaa@tpu.ru

Abstract — Implementation of CDIO approach into teaching practice requires the use of both active teaching and learning methods and adequate assessment procedures. Traditional assessment methods and tools are not enough to assess the variety of skills defined by the CDIO Syllabus. Development of the effective learning assessment system with a variety of assessment methods to verify the achievement of students’ learning outcomes is the focus of this research.

The paper presents the module ‘Assessment of the students’ learning outcomes’ that was developed for the faculty of the Russian HEIs who are in process of modernization of programmes in accordance with the CDIO approach. The development and approbation of the module is discussed. The trainees’ feedback is analysed and the conclusions on further improvement of the module are drawn.

Keywords — assessment methods; learning outcomes; CDIO Syllabus; personal and interpersonal skills; formative and summative assessment.

I. INTRODUCTION

The main objective of implementation the CDIO approach in higher education is training of engineers who will be able to solve real-life complex engineering problems, create new products and systems, effectively communicate with society and operate complex systems and programmes. Assessment of students learning outcomes is the measure of the extent to which CDIO Standards are implemented in teaching and learning process. According to the CDIO approach there must be the effective assessment system with a variety of methods and tools to assess disciplinary knowledge, as well as personal and interpersonal skills, and product, process, and system building skills, as described in the CDIO Syllabus [1]. Using a variety of assessment methods increases the reliability and validity of the assessment data.

Is it enough to use the traditional assessment methods and tools (e.g. written/oral exams or different kind of tests) to assess the set of learning outcomes defined by the CDIO Syllabus? The traditional methods are effective for assessment of disciplinary knowledge but not for personal, interpersonal and design-implement skills. Each group of the CDIO Syllabus learning outcomes should have appropriate assessment tools and performance criteria to measuring the intended learning outcomes with greater confidence.

This paper presents an overview of the assessment methods, analyses their advantages and disadvantages and discusses their applicability for each of the CDIO Syllabus group. The analysis of the existing assessment tools was summarized by authors into educational module ‘Assessment of the students’ learning outcomes’. This module was developed as a part of the continuous professional development programmes (CPD) on implementation of the CDIO approach in engineering education. The audience of such CPD programmes is faculty and managers of the Russian HEIs who are in process of modernization of educational programmes in compliance with the CDIO Initiative.

The development of the educational module ‘Assessment of the students’ learning outcomes’ and trainees’ feedback on its implementation is discussed.

II. THE MODULE ‘ASSESSMENT OF STUDENTS’ LEARNING OUTCOMES’

The module ‘Assessment of the students’ learning outcomes’ was developed for the CPD programme ‘Applying CDIO Concept in Engineering Education’ [2] for faculty and managers of the Russian HEIs. For the time being, two rounds of the CPD programme were realized (1 round from January to May, 2014; 2 round from September 2014 to January 2015). Besides in May 2015, the module was introduced into another CPD programme ‘Applying CDIO Concept to modernization of bachelor programmes in engineering and technology’ that was designed for the TPU faculty who are in process of reviewing their programmes relative to the CDIO Standards. Thus, the module on assessment of learning outcomes designed with consideration of the requirements of the CDIO Standards and best practices of assessment was implemented as a part of two different CPD programmes. The content of the module including the approach to assessment of the CDIO Syllabus learning outcomes, the format of delivery and feedback analyses are discussed in following sub-sections. The intended learning outcomes, content, teaching modes for the module are presented in table 1.
TABLE I. MODULE 4.1. ‘ASSESSMENT OF STUDENTS’ LEARNING OUTCOMES’.

<table>
<thead>
<tr>
<th>Learning outcomes</th>
<th>After the completion of the module 4.1, the learner should be able to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>– demonstrate overview of formative and summative assessment methods (their advantages and disadvantages),</td>
</tr>
<tr>
<td></td>
<td>– develop formative and summative assessment methods consistent with learning outcomes,</td>
</tr>
<tr>
<td></td>
<td>– develop the effective assessment of the CDIO Syllabus learning outcomes,</td>
</tr>
<tr>
<td></td>
<td>– understand the need to improve the assessment methods and the assessment system</td>
</tr>
</tbody>
</table>

| Content | – Assessment basics: overview of different assessment types and methods, their advantages and disadvantages. Group based project exam with individual assessment. Rubrics. |
|         | – CDIO Standard Eleven: learning assessment |
|         | – Development of learning assessment system: main phases |

| Format of delivery | 1. Interactive presentation with discussion on effective assessment of personal and interpersonal skills, and product, process, and system building skills, as well as disciplinary knowledge (2 hours) |
|                    | 2. Exercise: assessment methods (2 hours) |
|                    | 3. Interactive presentation on development the learning assessment system for a programme / course (2 hours) |
|                    | 4. Individual assignment/project: development of the assessment methods and performance criteria for learning assessment (10 hours) |

| Deliverables | 1. Overview of the assessment methods |
|             | 2. Learning assessment system for a course/project/programme |

A. Assessment basics: principles & types

The assessment system is the most powerful factor influencing students’ learning process. It can be used strategically in order to enhance students’ learning outcomes [3]. The assessment system is the key element of teaching and learning process since it helps:

- **students** to successfully fulfill the programme and gain new knowledge and skills
- **instructors** to improve the course/module and teaching methods used
- **HEIs** to make the decision on the effective use of financial resources
- **stakeholders** to evaluate the programme

The following sub-sections summarize main principles, types, methods and steps for planning the effective assessment system as it was developed for the module ‘Assessment of the students’ learning outcomes’ for CPD programmes. The two main principles of the assessment strategy are regularity and direct measurement.

- **Regularity**: means that assessment is done regularly to ensure the students are successfully achieve the intended learning outcomes. As a rule, students’ performance is assessed few times per semester, at the end of semester and upon completion of a course/module or entire programme
- **Direct assessment**: means that only intended learning outcomes (in terms of knowledge, skills and attitudes) must be subject to assessment. This principle is extremely important for planning the assessment system for a course/module and development the assessment and performance criteria.

There are three types of assessment: diagnostic, formative, and summative. The distinct difference between these three types of assessment is given below [4].

1. **Diagnostic assessment**: identifies the students’ ability and readiness to study a course or a programme as well as possible difficulties. Knowing students’ strengths and weaknesses can help you better plan what to teach and how to teach it. Diagnostic assessment is usually conducted in form of tests, self-assessments, discussions and brief interviews.

2. **Formative assessment**: is aimed to ongoing assessment of students’ achievements to provide the feedback and information during the instructional process, while learning is taking place, and while learning is occurring. Formative assessment measures student progress but it can also assess the progress of an instructor. A primary focus of formative assessment is to identify areas that may need improvement. Self-assessment and peer assessment are important elements of formative assessment since students may think more carefully about what they do and do not know, and what they additionally need to know to achieve the intended learning outcomes. Formative assessment also allows instructors to “rethink” and then “redeliver” material to ensure students are on track. Observations during in-class activities, reflections journals, question and answer sessions, self and peer assessment are more common forms for this type of assessment.

3. **Summative assessment**: gathers evidence at the end of an instructional event such as a major project, a course,
All three types of assessment are important at different stages of a course/programme planning. The selection of appropriate assessments and planning the assessment strategies should be done with consideration of course and programme objectives.

B. Assessment methods

This sub-section provides a brief overview of the assessment methods that are applicable for assessment of student learning in personal and interpersonal skills, and product, process, and system building skills, as well as in disciplinary knowledge. The analysis is mainly based on the overview of the best practices of assessment of learning outcomes of the some European, USA and Australian universities that implement the CDIO Initiative and problem-based learning (PBL) [5,6,7,8].

The module included the two-hour exercise on assessment methods. The trainees were given the description of different assessment methods including advantages and disadvantages and the four groups of the CDIO Syllabus learning outcomes. The objective of this exercise was to study the assessment methods and to choose the appropriate methods for assessment of the proposed learning outcomes. The following assessment methods were proposed for the exercise:

1. Written surveys. Asking individuals to share their perception about the study target – their skills/attitudes, or programme/course attributes. Advantages: can cover a broad range of attributes within a short period of time; provide accessibility to individuals who otherwise would be difficult to include in assessment procedure (alumni, employers); can provide unique stakeholders input. Disadvantages: results are highly dependent on wording of items (good surveys are quite difficult to construct); some surveys have low response rates; forced response choices may not provide opportunities for respondents to express their true opinion. Surveying is a relatively inexpensive way to collect data on important evaluation topics from a large number of respondents.

2. Interviews. Asking individuals to share their perception about the study target – their skills/attitudes, or programme course attributes in a face-to-face dialogue. Advantages: allow asking more personalized questions; provides immediate feedback; can include more items than it is possible on surveys. Disadvantages: requires direct contacts which may be difficult to arrange; results are highly dependent on wording of items; time consuming especially if many persons are to be interviewed. Interviews can cover a broad range of content and to interact with respondents. Opportunity to follow up respondents is valuable. It should be noted that both written surveys and interviews are widely used for assessment for programme learning outcomes rather than those for separate courses.

3. Student portfolio. Collections of multiple students’ work samples usually compiled over time and rated using the rubrics. Advantages: can be used to view learning and development in long perspective; allows measuring different skills at the same time (critical thinking, writing, research skills); samples in a portfolio are more likely than test results reflect students abilities; avoids “test anxiety”. Disadvantages: can be costly in terms of evaluator time and effort; management of the collection and scoring process, including development of the valid rubrics is challenging. Portfolios are good for multi-purpose assessment.

4. Simulations. Assessment of students’ skills in “real-life” settings. Simulation is primarily used when it is impractical to observe a person performing a task in a real world situation. Advantages: excellent means for evaluating depth and breadth of student skills development than other tests or performance-based measures; more flexible since simulation can be arranged for virtually any student target skill. Disadvantages: the behavior observed or performance appraised may not be typical because of the presence of the others; usually requires additional effort in planning and preparation.

5. Performance Appraisals. Systematic measurement of demonstration of the acquired skills usually conducted in real-world situations (during the project work or students’ internship). Advantages: provide a direct measurement of what has been learned; go beyond paper-and-pencil tests and other assessment tools in measuring skills. Disadvantages: ratings of student performance are more subjective than tests; requires considerable time and effort. Generally, a performance appraisal is the highly valued but costly form of assessment of student learning outcomes.

6. External Examiner. Invitation of an expert in the field, usually from another HEI to supplement the assessment of students’ learning outcomes. Advantages: increases impartiality; useful feedback for both students and programme evaluation; outsiders can ‘see’ skills and attributes to which insiders get accustomed. Disadvantages: there is a risk of misfit between examiner’s expectations/expertise and students’ learning outcomes. It is better to use external
examiner a supplement to other assessment methods to enhance external validity, but not as primary assessment option.

7. Written and Oral Exams. Written examinations include as a rule multiple-choice and other closed items, calculations, and open-ended questions. Instructors map written examination questions to course learning outcomes and to examine students’ achievement in light of these outcomes. Advantages: effective and efficient means to assess students’ conceptual understanding; allow assessing a large number of students in the same time period. Disadvantages: good questions are difficult to construct, and students’ answers do not always reveal the causes of their errors. Oral examination is an assessment of students’ knowledge level through face-to-face dialogue between student and instructor. Advantages: oral questions enable faculty to uncover students’ misconceptions; require that students think on their feet and speak coherently; dialogue format decreases misunderstanding in both questions and answers; allow assessing students thinking and speaking skills along with knowledge; direct implications of results for course/programme improvement. Disadvantages: costly in terms of time and effort; requires considerable coordination during various phases of development.

8. Observations. Measurement of student performance in a natural setting with non-interactive methods. Advantages: catching students being themselves is the most ‘natural’ form of assessment. Disadvantages: there is always some risk of confounded results due to ‘observer effect’ (subject may behave atypically if they know they are being observed). This is the best way to know what students actually do, how they manifest their attitudes and values.

9. Self-assessment and Peer assessment. These assessment methods are extremely important since they increase students’ responsibility and autonomy and change the role of the student from passive learner to active leaner and assessor. Peer assessment presumes that students individually assess each other’s achievements/contributions using a predetermined list of criteria. Advantages: encourages students to reflect on their role and contribution to the process of the group work; focuses on the development of student’s judgment skills; can help reduce the ‘free rider’ problem as students are aware that their contribution will be graded by their peers; provides more relevant feedback to students as it is generated by their peers. Disadvantages: students often award everyone the same mark; students have no experience in assessment; students sometimes reluctant to make judgements regarding their peers. Self-assessment works well with PBL. It allows students to think more carefully about what they do and do not know, and what they additionally need to know to achieve the intended learning outcomes. Self-assessment has similar advantages and disadvantages as peer assessment.

10. Group based exam with individual assessment. This method is widely used at Aalborg University (Denmark) to assess the group projects. It is one of the best methods for assessing interdisciplinary projects fulfilled by a group of students. It is an oral examination based on a written report. The students present their project and subsequently, facilitators and external examiners comment on their communication skills and assess whether the presentations serve to clarify or add something new to the written report. The facilitators and external examiners ask questions to the team members related to their report, and the team members have the opportunity to answer the question or elaborate on a point made by one of the students. Finally, after voting, the team members receive an individual grade. The report serves as a point of reference for differentiating the individual grades, which are based on the oral presentation and the performance during the questioning part.

Having discussed pros and cons of the proposed methods within small groups, the faculty members aligned the four groups of the CDIO Syllabus learning outcomes with the assessment methods. The result of such ‘alignment’ is shown in Table 2.

<table>
<thead>
<tr>
<th>CDIO Syllabus</th>
<th>Focus of assessment</th>
<th>Assessment methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Disciplinary knowledge and reasoning</td>
<td>Underlying knowledge of mathematics and science, core and advanced engineering fundamental knowledge</td>
<td>Different kinds of test, written and oral exams, written survey and interview, invitation of external examiner</td>
</tr>
<tr>
<td>2. Personal and professional skills and attributes</td>
<td>Students’ skills in solving atypical problems, conducting experiments, system, creative and critical thinking, ethics and social responsibility</td>
<td>Portfolio, peer and self-assessment, performance appraisal, observations, brainstorming</td>
</tr>
<tr>
<td>3. Interpersonal skills: team-work and communication</td>
<td>Effective communication with the society for problem-solving</td>
<td>Simulations, peer and self-assessment, performance appraisal, observations, written</td>
</tr>
</tbody>
</table>
### The CDIO Standard Eleven

- **Planning the learning assessment system.**

The second part of the module included brief overview of the CDIO Standard Eleven – Learning Assessment and the description of the four key phases of planning the assessment system [8]: 1) the specification of learning outcomes 2) the alignment of assessment methods with learning outcomes and teaching methods 3) the use of a variety of assessment methods to gather evidence of student learning 4) the use of assessment results to improve teaching and learning. The trainees were given the instruction on steps they need to undertake to thoroughly plan the effective assessment system.

| 4. Conceiving, designing, implementing and operating system in the enterprise, societal and environmental context – the innovation process | Understanding of societal context, the impact of engineering on society and environment, ability to find solutions for new problems, to create new products and systems and operate them | Group based exam with individual assessment, peer and self-assessment, performance appraisal, observations, written survey and interview, portfolio |

Some conclusions can be drawn based on an overview of the assessment methods:

- All the assessment methods have advantages and disadvantages
- The “ideal” method means those that best fit between programme needs, satisfactory validity and affordability (time, effort and money)
- No single method is good for measuring a wide variety of different students’ abilities
- It is crucial to use multi-method approach (especially to evaluate students’ projects) to maximize validity and reduce disadvantages of any approach
- It is important to test the method first to see if it is good for a course/programme, students and faculty
- It is important to use the results of self- and peer assessment to actively involve students into assessment process
- Students should be aware of the assessment procedure; the performance criteria must be clearly defined, achievable and measurable.
- It is important to have in place regular surveys and interviews to monitor the quality of a course, its content, teaching modes and assessment methods used by instructors.

Thus, the first part of the module included information on assessment basics, interactive exercise on aligning the CDIO Syllabus learning outcomes with the appropriate assessment methods, and wide discussion on a number of topic, such as the importance of formative assessment methods, use of the results of peer and self-assessment, tools for assessing students’ group projects (input of each student in the project work, assessment of disciplinary knowledge within the project).

### C. Planning the learning assessment system.

The practical part of the module included a ten-hour individual assignment/project on development of the assessment methods and performance criteria for learning assessment within a course/programme. To fulfill the project the trainees have to evaluate their programmes relative to the CDIO Standard Eleven, plan the assessment system for a programme including the continuous improvement of the programme, and plan the assessment of learning outcomes for a course or project. The main challenges that the trainees faced in completing the individual projects and the overall feedback for the module ‘Assessment of the students’ learning outcomes’ approbation are highlighted in following section.

#### III. FACULTY SURVEY RESULTS

The challenges that faced trainees in changing the existing assessment system while completing the individual assignment/project were summarized as the result of the surveys and interviews. The main difficulties are:

1. **Lack of time for the individual assignment.** The trainees needed much more time than it was allocated by the instructor. The reason is that evaluation of programme relative to Standard 11 was quite new for the trainees and they needed time to analyze the programme documentation and interview colleagues to fill in the tables. However all the trainees pointed out that the work done revealed the important aspects of programme design that had not been previously taken into account.

2. **Lack of time for theoretical part of the module.** The trainees noted that they needed more time to study the assessment methods in details.

3. **Lack of handbooks** on planning the assessment system.

4. **Lack of practical examples** illustrating the assessment of students’ learning outcomes and planning the assessment system.

5. **Lack of immediate feedback** while completing the individual assignment.

Nevertheless, the individual assignment is the important part of the educational module ‘Assessment of the students’ learning outcomes’ that is aimed at acquisition of practical skills in planning the effective learning assessment system in accordance with the CDIO approach. Here is the quotation of one of the trainees received as a result of the survey: ‘Planning the learning assessment system is the extremely important task. The results of the work done confirm that the effective assessment system should be implemented into teaching and learning process (no matter the programme is
developed in accordance within the CDIO approach or not). The review of the existing assessment system revealed the problems and the knowledge acquired in the module should be taken into account to resolve these problems.

It is recommended to allocate more than 10 hours to fulfill the assignment (probably from 16 to 20 hours). Besides, the operative feedback mechanism must be in place to discuss main difficulties trainees face in completing individual assignments.

In order to evaluate the overall quality of CPD programme, the trainees were asked to measure from 1 to 5 (five is the highest on the scale) the following programme aspects: relevance - to what extend the subject of the section is relevant for modernization of engineering programme, practical importance - to what extend the materials of the section and acquired knowledge and skills will be used, and novelty - to what extend the content of the section systematizes and enlarges the knowledge of programme participants in corresponding fields. For module ‘Assessment of the students’ learning outcomes’ the figures were 4, 67 for relevance, 4, 42 for practical importance and 4, 2 for novelty. Such data confirm the importance of the assessment issues for faculty of Russian HEIs.

IV. CONCLUSIONS

The CDIO approach assumes that the effective system with the variety of assessment methods must be integral part of the educational process to ensure students’ achievement of the intended learning outcomes. The approbation of educational module ‘Assessment of the students’ learning outcomes’ is a real step towards creation of learning assessment systems in Russian HEIs. Despite the difficulties and challenges the faculty faced in making steps from theory to practice, they recognize the importance of development the effective system ensuring the assessment of CDIO Syllabus learning outcomes with greater confidence. The trainees’ feedback results are analysed and taken into account for further development of the module.

REFERENCES