The Impact of Competency-Based Learning and Digital Self-assessment on Facilitating Students' Cognitive and Interpersonal Skills

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Abstract This paper aims to utilize a mixed-methods assessment for an innovative interdisciplinary course, Application Period, in a world-class Russian University. In order to examine how the cognitive (competency-based learning) and motivational (self-efficacy for interpersonal skills) concepts impact students' achievement in engineering education, an exploratory sequential design was conducted by firstly collecting qualitative data to signify the students' interactive learning process during the project-based collaboration and team communication. Subsequently, two instruments measuring the students' learning outcomes were built based on the previous qualitative data and preliminary learning objectives. The suggestions and implications are provided to specify how to employ competency-based learning and self-efficacy for interpersonal skills in teaching and how to assess those content knowledge and pedagogical skills in contemporary education.

Keywords Competency-based learning · Self-efficacy · Assessment · Mixed-methods

1 Introduction

Cognitive science in the sense of how individuals effectively acquire, construct, and transfer knowledge is a significant line of learning in science, technology, engineering, and mathematics (STEM) education. Specifically, scientists and educational researchers have actively engaged in exploring how innovative teaching-learning strategies and pedagogies facilitate students' academic achievement and how per-

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formance assessments would accurately measure students' learning outcomes and provide reliable interpretations of students' learning effectiveness and efficiency [1].

Numbers of studies have specified that today's students, whether they be engineering, science, medical, or education, must acquire not only technical knowledge but also a broad body of disciplinary knowledge specific to their field [2]. The Accreditation Council for Graduate Medical Education (ACGME) and The American Board of Surgery for example, have recently instituted the Milestones Project for General Surgery Residency (ABS) training. ACGME and ABS have identified approximately 70 *milestones* that they believe reflect what surgeon's must be able to do effectively. Surgical residents must demonstrate they are meeting these milestones throughout their 5–7 years of training. These milestones fall within 6 competencies including, patient care, medical knowledge, practice-based learning and improvement, systems-based practice, professionalism, and interpersonal and communication skills. In other words, besides gaining technical skills and disciplinary knowledge, we now recognize that students—both engineering and surgery—should learn how to construct, process, and apply fundamental knowledge by using cognitive strategies, analytical reasoning and problem-solving skills in authentic learning environments. Furthermore, they need a wide array of learning opportunities to practice personal and interpersonal skills that will allow them to function effectively and efficiently in real engineering teams and to create innovative impact to ecosystem.

Therefore, we began by asking to what extent can instructors make teaching and learning more effective for engineering related courses? It is undoubtedly that intrinsically motivating students (e.g., increase students' curiosity or interests) to engage in high level of cognitive learning (e.g., problem-solving skills) through authentic environments is significant in effective teaching and learning settings [3, 4]. However, how do instructors practically design and deliver engineering courses to motivate and facilitate students to actively and intrinsically engage in cognitive learning? Particularly, the questions most educators and researchers wonder in engineering education have being focused on how to embody the pedagogy of authentic learning and active learning into content knowledge teaching (e.g., the lectures including heavy abstract mathematical concepts, such as quantum physics) and interpersonal skill learning (e.g., teamwork and communication) to optimize teaching-learning effectiveness. Thus, the purpose of this study is to investigate how the cognitive (i.e., authentic learning) and motivational (i.e., self-efficacy) strategies impact interdisciplinary learning in engineering education.

2 Perspectives

Based on cognitive learning theories, in order to effectively comprehend, build, retrieve, and apply learned knowledge and skills, we believe students should engage in active rather than passive learning by participating in collaborative activities and by thinking about and elaborating on their communication practices. In short, authentic learning is important because it helps learners to connect the new information with their prior knowledge by constructing and representing the integrated ideas during collaboration and communication with others who are also experiencing real-world problems. The learning process of identifying new concepts, selecting appropriate strategies, and analyzing the consequences for authentic problems is the key element of scientific approach for successful learning achievement.

Furthermore, among several motivational factors, personal causality operates as a cognitive dynamic phase based on motivation, emotional activation, and, schematic processing of decision-making [3, 5]. The quality of effort in terms of individual engagement toward accomplishing tasks has been strongly linked to self-efficacy [3]. For that reason, it is difficult for an individual to achieve successfully when they doubt their ability. Briefly, successful performance is thus determined by an individual's judgment of his/her ability within a subject and the belief that individual has that he/she can accomplish a specified task given that skill level. Then, based on the positive mastery experience, the judgments of learners' self-efficacy would impact their choices of activities and level of engagement. That is to say, in a teaching-learning setting, the lack of self-efficacy may result in learners' negative attitudes and low achievement.

As a result, with the need of contemporary disciplinary knowledge and skills in engineering education, teachers must begin to help students achieve intended learning outcomes and meet enterprise and societal needs by applying the fundamental knowledge and skills to solve real-world problems and increase their self-efficacy for certain domain knowledge. However, how do educators construct meaningful intended learning outcomes and embed active learning into the curriculum to increase the students' learning achievement in an effective pedagogical method? Furthermore, which validated methods of assessment can accurately evaluate students' actual learning outcomes and reflections in engineering education? Accordingly, there is an increasing need for educators and researchers to explore how to measure if students efficiently gain technical knowledge and skills and effectively utilize personal and interpersonal skills to function in real scientific teams and produce innovative products and systems.

2.1 Building the Innovative Interdisciplinary Studies

In order to foster engineering students in transferring knowledge and applying learned skills in authentic situations, a 1-week *Application Period* interdisciplinary course was designed, developed, and implemented to focus on innovative activities in a Russian University located in Moscow. This new private graduate university was founded in collaboration with Massachusetts Institute of Technology (MIT), which co-designed and co-implemented the curriculum and courses in the fields of energy, space, nuclear, biomedical engineering, and product design and manufacturing. The aims and pedagogies of the university curriculum are to address critical scientific, technological, and research-based knowledge to foster innovation in education and research.

The infrastructure of each academic semester is a 6-1-1-curriculum (8 weeks) design for a full term. The standard 8-week term includes an instructional period with teaching and learning activities for 6 weeks, a 1-week summative assessment, and a 1-week Application Period at the end of each term. Specifically, all formal instruction will be completed before the Friday of week six for each term. During weeks 1–6, the teaching and learning activities are focused on engaging students in gaining fundamental disciplinary knowledge in science, technology, mathematics, and engineering. The summative assessment that takes place during week 7 is designed to let students demonstrate and reflect on what they have learned by completing a series of formative assessments. Each course has its summative assessment, and the course instructor is responsible for designing and developing the assessment that can be written, oral, hands-on, or a suitable combination of learning achievement evaluation.

The week 8 Application Period is designed to provide students with interdisciplinary studies and authentic learning experiences. It provides students opportunities to combine two or more disciplines into one final project and to engage in hands-on activities that reflect real-world problem solving. The final project requires students to apply the fundamental engineering content knowledge they have learned from the previous 6-week instructional term. It also includes multiple opportunities for students to apply theme-based interpersonal skills (e.g., communication) based on the university Learning Outcomes Framework.

2.2 The Learning Outcomes Framework for Application Period

The CDIO syllabus [6] pedagogy, which stands for conceiving, designing, implementing, and operating, has played a key role and framework for the design of intended learning outcomes of the *Application Period* course. Much like the General Surgery Milestones project, the CDIO framework is designed to set curriculum benchmarks and also to capture the needs of engineering researchers, students, educators, and stakeholders to integrate innovation, research, and education in a pioneering international university for bringing about entrepreneurial impact in society. For example, the Learning Outcomes Framework [7] of the Russian university was developed and customized in four sections of educational learning outcomes: (1) disciplinary knowledge and reasoning, (2) personal attributes—thinking, beliefs, and values, (3) relating to others—communication and collaboration, and (4) leading the innovation process.

In addition to the hands-on and innovation capability, students are required to develop and apply personal and interpersonal skills in Application Period. According to the university Learning Outcome Framework, the personal skills

Table 1 Themes of personal and interpersonal skills for each application period

Terms	Students	Themes (based on the learning outcomes framework)
Fall Term 1	1st year	3.1 Communications—oral presentation and discussion
	2nd year	3.1 Communications—written, electronic and graphical communication
Fall Term 2	1st year	3.3 Teamwork
	2nd year	3.4 Collaboration and change
Spring Term 3	1st year	2.1 Cognition and modes of reasoning
	2nd year	2.3 Ethics, equity and other responsibilities
Spring Term 4	1st year	2.2 Attitudes and learning
	2nd year	3.2 Communications in international environments

include cognition, modes of reasoning, attitudes and learning, ethics, and equity. The interpersonal emphasis includes communication, collaboration, and teamwork skills. Each Application Period is focused on different themes from the personal and interpersonal learning outcomes (see Table 1) and a facilitator would co-teach the learning activities for the special theme for each term. For example, the theme of first Application Period was "communication (oral presentation and discussion)". Therefore, besides the hands-on project, students had the extra learning activities and direct feedback and interaction with the facilitator advising effective communication skills.

3 Methodology

Due to the innovative design and integrated learning outcomes of Application Periods, it is imperative for engineering educators and researchers to understand the notion of "what works" and also to be able to select the strategies that "work the best" for emphasizing the instructional values, curriculum goals, logistical constraints, and student expectations. That is to say, one data source alone is insufficient to explain the interrelated components of the design and implementation of the Application Period. Additionally, in order to be responsive to new insights of an innovative engineering application, a rich assessment based on solid theoretical standpoint needs to combine participants' and researchers' perspectives through revealing meaning by qualitative approach and uncovering relationships between variables by quantitative instrument and analysis [8]. For that reason, a mixed methods research design should play the role effectively.

3.1 A Mixed Methods Design

This mix-methods assessment is an exploratory sequential design. The sequential design began with collecting qualitative data including observation notes, pictures, and videos of group discussion during the hands-on activities to represent the learning process of students' teamwork and communication Subsequently, a quantitative data collection including two instruments was built based on the previous qualitative data and the intended learning outcomes (Fig. 1 shows an example).

3.2 Participants and Procedures

Fifty-seven graduate students participated in the first two Application Periods (i.e., App 1 and App 2) to engage in hands-on learning activities with domain experts. The teaching and learning activities included instructional lectures for design and communication, group brainstorm sessions, team collaborations and presentations, and hands-on projects. The data collection began with writing the observation notes that were based on the daily learning topics and activities, instructors' interactions with the students (questions and responses), students' specific learning behaviors, learning materials and environments. The observation notes include a rubric system to measure students' interactions with the instructors and peers based on the "personal and interpersonal" Learning Outcome Framework. Each category was scaled from ineffective (1), developing (2), accomplished (3), and exemplary (4) based on the level of interactions between the instructor(s) and the students during the teaching and learning activities. Additionally, multimedia data (e.g., pictures and videos) were also collected.

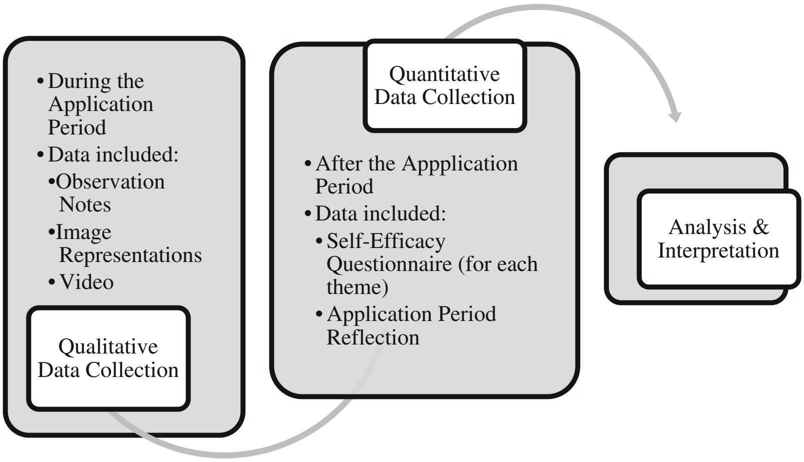

Fig. 1 The exploratory sequential design

Based on the exploratory qualitative results, a quantitative phase was designed and conducted to generalize the initial findings. Specifically, after the qualitative stories and data about the students' learning experiences and interactions with the instructors and peers to identify the conditions, consequences, and the learning outcomes, the categories were emerged from the qualitative data as variables. Thus, the quantitative instruments were developed and used to assess the self-efficacy for the specific theme of each term and the overall learning outcomes of the Application Periods.

4 Results

4.1 Qualitative Data

The qualitative data including collecting observation notes, images, video clips, and informal interview with the instructors and the students were analyzed and coded based on the Grounded Theory. Based on the analysis and coding method, several themes were emerged from the Application Periods (Fig. 2 shows the themes).

4.2 Self-efficacy Questionnaires

Application Period One—Oral Communication. The tasks as described include both formal communications, such as defining the speaker's objectives, the audience's expectations, and informal communications. In general, student confidence

Fig. 2 Word cloud of the emerged themes from application period

in their communications skills increased substantially over the eight days of the Application Period. The smallest change was a 7.0 % increase in the ability to identify speaking objectives, which was not a statistically significant change. Changes in confidence in all other capabilities demonstrated positive increases that were statistically significant.

The greatest changes in oral communications confidence are those marked by changes that increased from 16 % to almost 25 %, and are significant at the 0.001 level of probability. They include the ability to develop an appropriate style of speaking for a given audience (21.8 %), to select a style of presentation in general (a change of 20.3 %), and more specifically to use voice quality and eye contact (increasing 16.6 %), and being able to answer questions effectively (an increase of 19.7 %). The greatest improvement of 24.6 % was the student's confidence to be able to combine media for a talk, an activity that was demonstrated in final presentations at the end of the Oral Communications program (Fig. 3 shows the details).

Application Period Two—Teamwork. The greatest changes in self-efficacy for teamwork are those marked by changes that increased around 20 %, and are significant at the 0.001 level of probability (Fig. 4 shows the details). They include the ability to work effectively with dislike team-members (21.3 %) and be accountable (18.2 %).

Students' Feedback (Open-Ended) Survey. At the end of each Application Period, the participants were asked to answer their learning satisfaction in terms of their Application Period experiences. The survey included 6 items (Fig. 5 shows the details) on the scale of 1–5, with 1 being "not at all positive" to 5 "extremely positive". Particularly, one item referred to "2.x/3.x skills" means the interpersonal skills from the university Learning Outcomes Framework.

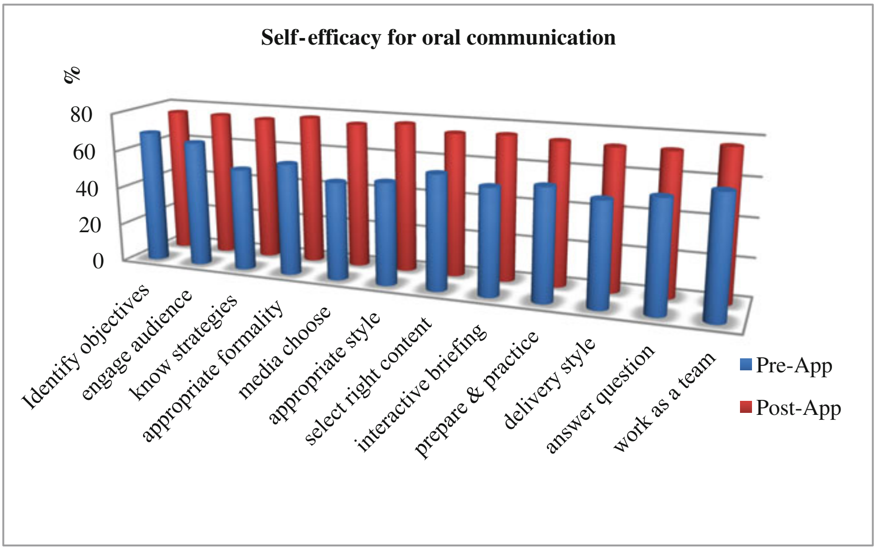

Fig. 3 Students' self-efficacy for oral communication for application period one

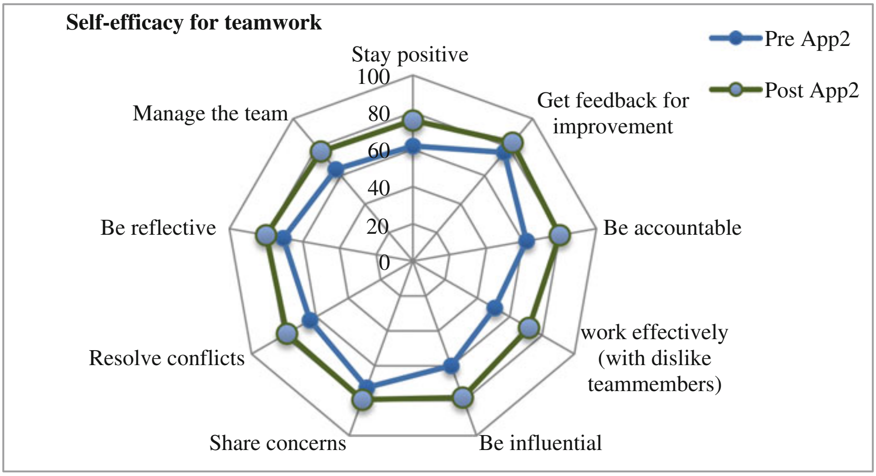

Fig. 4 Students' self-efficacy for teamwork for application period 2

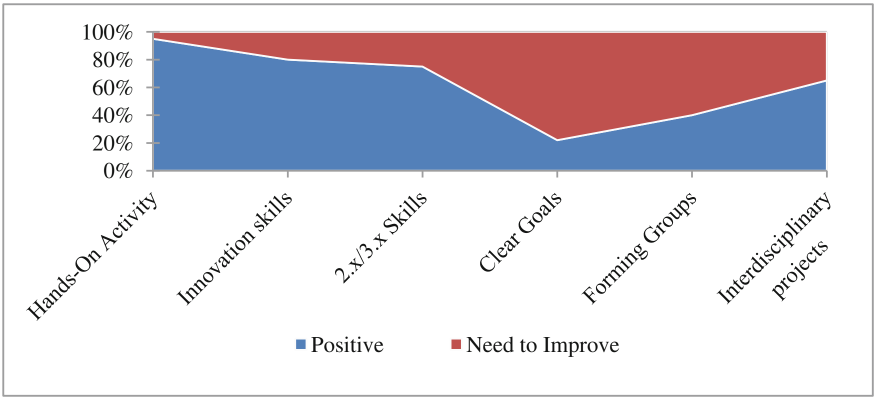

Fig. 5 Students' feedback survey

5 Discussions and Implications

The present study combined qualitative and quantitative methodologies to provide significant information that helps examine how authentic learning and self-efficacy for interpersonal skills impact learning achievement in interdisciplinary engineering education. The results of this study have verified the main themes and connections between the CDIO Learning Outcomes Framework and the pedagogies for the interdisciplinary studies program: *Innovation and Hands-on capability (authentic cognitive learning)*, *Goal-setting* (motivation), and *Teamwork and Leadership* (interpersonal skills).

5.1 Using Self-efficacy for Interpersonal Skills as an Assessment in Engineering Education

Unquestionably, it is important for educators to build students' knowledge of the content in engineering. However, doing so without considering increasing interpersonal skills may do little to improve students' learning effectiveness. Personal factors, such as enthusiasm and creativity, may positively influence attention to memory for new knowledge, and thus increase self-efficacy [3]. That is to say, it might be efficient to raise an individual's self-efficacy through the process of communicating and team building and facilitate learning effectiveness.

5.2 Assessing the Intended Learning Outcomes of the Application Period

In engineering education, the dynamics of current curriculum focus has been constructed through an ongoing process of focusing on how students learn mathematics more effectively based on cognitive thinking and reasoning, which are the significant elements in self-regulated learning. Self-regulated learners are intrinsically motivated to engage in setting goals for themselves, finding effective strategies to achieve their goals, monitoring the process of their strategic thinking and reasoning, and evaluating the self-initiated metacognitive learning process. In this study, the Russian engineering students were intrinsically motivated and interested in the process of authentic learning (e.g., creating prototypes in energy consumption for solving real-world problems). Specifically, the final presentation for the Application Period to the public played a significant role in motivating students to participate and complete the project. They saw the final presentation as a great opportunity to get feedback and let peers, administrators, or industrial business to acknowledge their work.

Finally, when the students engaged in "collaboration" or "group discussion", the immediate feedback and meta-cognitive prompt from the facilitator is a critical indicator for students' learning achievement in engineering education. However, teaching "Teamwork" and how to "Collaborate" is a challenging topic in engineering education. Numbers of students reflected that they did not know how to work with the people they didn't agree with or they didn't like. Some students were just enforced to give up participating because their opinions were not accepted. Instructional designers, instructors, and researchers in the related filed may need to focus on elaborating what "collaboration" or "teamwork" is and why it is important for students to work on besides designing and prototyping products. It shouldn't be just "catching" students not participate. It's about educating them how to respect others' opinions and how to be an innovative entrepreneur (with pedagogies and values).

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