

Learner-Centered Engineering Education as an Incubator of 21st Century Skills*

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Educational institutions aim for preparing students for their future lives. Yet, most schools focus on teaching static knowledge rather than fostering social and personal competences required in the 21st century. This paper proposes a self-driven, learner-centered approach to education named “learning office”. Existing literature is reviewed and a questionnaire estimating selected 21st century skills is developed. A survey employing the questionnaire was conducted with 12 cohorts of the grades 9–11 of an Austrian higher technical secondary vocational school. Six cohorts were taught in the new approach. The analysis of the 312 responses showed that learning office students reported significantly higher overall scores in critical thinking, self-efficacy, personal responsibility, and openness at grade 10. Learning office students were also significantly more likely to provide a meaningful written reflection. We conclude that the learning office approach indeed fosters 21st century skills.

Keywords: 21st century skills; learner-centered education; learning office; student-centered learning; upper secondary school level

1. Introduction

The ongoing digital transformation and the resulting transition from an industrial era to a knowledge age substantially impact today’s workplaces: Knowledge workers are required to adapt to fast-changing environments, learn new technologies on a regular basis, work with and critically evaluate a considerable amount of permanently available, but potentially short-living information, and communicate as well as collaborate in virtual environments [1–4]. Since educational facilities aim to prepare students for professional life, the skills required by modern workplaces in the 21st century should be part of students’ education [2–6]. Yet, it seems that most schools exclusively focus on teaching subject-related knowledge and cognitive learning outcomes, although the importance of 21st century skills has long been acknowledged in the business sector [2, 3, 6–9].

This contribution is based on previous work [2–4, 6, 9–11] and evaluates the long-term school pilot project called “learning office” regarding its suitability to foster 21st century skills. Using a self-directed approach, students acquire additional social and personal competences, which prepare

them for modern worklife and higher education [2–4, 6]. In particular, the 21st century skills students acquire in the learning office provide a foundation for a successful course of studies in the field of engineering education: In addition to the subject-specific IT skills prescribed in the curriculum, graduates of the learning office have mastered the ability to learn independently after five years of daily practice, which is especially important in the field of computer science due to its fast-paced nature and ever-changing technology. Furthermore, being self-responsible and organizing one’s own learning belong to the most essential skills of university students. In this article, we briefly review existing literature about the learning office project, develop a questionnaire to estimate selected 21st century skills we called self-evaluation of personal competences (SEPC), and present the results of the questionnaire survey we conducted in 12 cohorts at the grades 9–11, comprising 312 respondents.

2. Background and Terminology

2.1 Employability and 21st Century Competencies

The learning office aims to enhance our students’ employability by fostering the acquisition of social

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and personal skills expected in the 21st century [2–4, 6, 9]. Van der Heijden developed a five-dimensional model of “professional expertise”, which devotes three dimensions to social and personal skills [12]. Her approach was enhanced to define the five dimensions of employability [13], four of which include typical 21st century skills. This highlights the important contribution of these skills to the overall employability of an individual.

The relevance of non-cognitive skills has long been recognized in the field of person-centered learning, which is the basis of the self-directed learning office approach [3, 4, 6, 9, 11]. Rogers, a pioneer in student-centered learning, highlighted the need for being able and willing to adapt to change 52 years ago [14]. Freiberg extended the work of Rogers [8] and expressed his critical thoughts on modern education: “The business community realizes what too many school policy-makers have failed to understand: People working together make the difference” [8, pp. 264–266]. This point of criticism seems to remain valid after 25 years: Sin and Neave found that European employers felt that academic achievement is not a sufficient indicator of the employability of graduates [7]. The question arises as to which skills are expected from graduates in the modern world and how those competences can be taught. The research and work of Trilling and Fadel address precisely this set of skills, which they call “21st century skills” [5], namely “career and life skills” [5, p. 73], “digital literacy skills” [5, p. 61], as well as “learning and innovation skills” [5, p. 49].

The literature in the field of engineering education confirms the relevance of these kinds of skills to modern engineers. McMasters discussed current practices and the future of educating engineers from an industry perspective and presented an idea of a “‘well-rounded engineer’ for the 21st century” [15], which encompasses not only technical and engineering skills, but also professional and business skills, including team work, networking, communication, interpersonal skills, as well as organizational skills such as scheduling and planning. Chan et al. stated that “the technical knowledge taught in universities is barely sufficient to deal with the rapid change in today’s business environment” [16] and shared a concept for teaching creativity and innovation. Additional research in engineering education addressed the investigation of students’ self-directed learning readiness [17], communication skills and ability to learn [18], as well as responsibility for one’s own learning, problem solving, and working with others [19].

At European level, the European Digital Competence Framework for Citizens (DigComp) has been developed by the Joint Research Centre (JCR)

since 2013 to offer a framework and guidance to improve European citizens’ digital competences required in the modern world [20]. The DigComp framework contains the five competence areas “information and data literacy”, “communication and collaboration”, “digital content creation”, “safety”, and “problem solving”. A recent report on the connection between digital competences and employability summarizing several case studies, statistics, and stakeholder opinions by the JCR stated that it is expected that about 65% of the pupils currently registering for primary school will work in completely new types of jobs that are not yet in existence [21]. Hence, the most requested skill based on an analysis of online job advertisements of the EU member states is “adapt to change” [22], which corresponds to Rogers’ suggestion of “changingness” as goal for education more than 50 years ago [14].

Van Laar et al. conducted a survey among 1,222 professionals in the Netherlands and found that self-directed learning positively contributed to five of the ten investigated skills [23]. At the same time, they found educational attainment connected to only one of the ten skills among one of the investigated groups [23]. Therefore, self-directed approaches seem suitable for promoting 21st century digital skills.

The learning office approach therefore tries to close this “employability gap” using a self-directed, student-centered approach [6]. To explore the effects of the learning office on our students, we decided to investigate not only 21st century skills, but also attributes related to the personality of students. We therefore aimed to analyze the following skills and traits:

Critical thinking (CT): Critical thinking is seen by many as the new basis of 21st century learning and is subject of ongoing research [23, 24]. It partly maps to the problem solving competence area of the DigComp framework [20].

Communication (CO): Trilling and Fadel [5], the DigComp framework [20], as well as current research [23, 24] see communication as integral part of 21st century skills.

Self-efficacy (SE): A person’s self-efficacy plays an important role in the concept of self-regulated learning [25]. Its connection to learning and performance are subject of current research [26, 27].

Reflective thinking (RE): Since self-reflection is also part of the process of self-regulated learning [25], we aimed to investigate our students’ reflective thinking ability.

Personal responsibility (PR): In times of social distancing, climate change, data protection, copyright laws, and social media, each individual assumes personal responsibility. We were therefore

interested in whether the learning office has an effect on this attribute.

Openness (OP), agreeableness (AG): Besides typical 21st century skills, we were also interested in potential differences in our students' personality traits and chose to explore their openness and agreeableness, two of the five big personality traits.

Uncertainty tolerance (UT): Due to rapidly emerging technologies, uncertainty and its tolerance are a growing area of interest in health care research [28]. Since the IT sector is also known for short-living technologies, we also investigated our students' tolerance of uncertainty.

2.2 The Learning Office Approach

The learning office builds on the principles of person-centered and student-centered learning [2–4, 6, 11] and is based on Rasfeld's approach, who proposed the learning office approach in her books [29, 30]. The learning office has been extended to computer science education and higher grades by introducing another branch to the higher IT department of the TGM [3, 4, 6, 11, 31], an Austrian public upper secondary vocational school (K9–K13). When students register for our department, they may decide whether to be taught in traditional classrooms or the learning office. Learning office students have flexible class schedules that allow choosing between multiple subjects on most school days. Since multiple cohorts have simultaneous learning office lessons in the same rooms, peer learning across different grades is enabled and promoted. During learning office hours, a teacher is available in the room ("office") of the respective subject and supports students as a coach.

Recent findings revealed no significant differences regarding student performance between the learning office and traditional classrooms after the first school year [2, 6, 11] – we even found a reduced drop-out rate and better results in some subjects in the learning office. Therefore, a gain in 21st century skills would be an additional asset of the learning office students. It has already been discovered that learning office students cooperate more, like attending school more, experience a better support from teachers, and appreciate their classrooms more [6, 11]. In this paper, we investigate students' development of 21st century skills, addressing the following research questions:

RQ 1: How can 21st century skills be feasibly estimated using a self-report research instrument?

RQ 2: Which statistical model lends itself to describing the estimated 21st century skills?

RQ 3: Is the constructed research instrument valid and reliable?

RQ 4: Do students taught in the learning office report different levels of 21st century skills compared to students in traditional classes?

3. Material and Methods

3.1 Study Setup and Design

The setup of the research framework has been outlined in previous work [3, 6, 11]. Since our students and their parents may choose between the two approaches, we do not control group assignment, which is typical for an observational study design [32]. Embedded within that observational study, multiple small-scaled quasi-experiments are conducted in the form of centralized exams and other research instruments.

We reviewed the literature on the assessment of personal and social competences. Rotheram-Fuller et al. analyzed existing studies which aimed to foster social skills of students with autism spectrum disorders [33]. They identified different sources of assessment data: "parent report, teacher-report, peer-report, self-report [. . .], direct observation [. . .], and video observations" [33, p. 2]. Due to the high effort to rate, observe, and code the behavior of hundreds of students, we ruled out observations as well as teacher reports as practicable source for quantitative data. Parent reports imply additional effort for the caregivers, which would lower the response rate and introduce bias. Peer-reports require complex algorithms to assign fair peer reviews in this setting. We therefore decided to use a self-reported approach due to its simplicity to collect large amounts of data, and complement it with other instruments in the future if necessary. To maximize the response rate and motivate students to answer honestly, the survey should be anonymous and answerable within 15 minutes. We therefore had to keep the number of questions to a minimum, which is why we purposely picked a subset of the statements of well-established questionnaires. Furthermore, the statements should be suitable for school students of the grades 9–11.

Sarigoz developed a questionnaire comprising 21 Likert questions aiming to estimate students' self-perception of their *critical thinking* ability [34]. He conducted a study with a sample of 722 high school students including a validity study. We evaluated the 21 statements for their use in our school context, selected seven statements we found suitable, and translated them into German with friendly permission of the author, namely the statements 3, 5, 9, 10, 13, 17, and 21 [34, pp. 5318–5319].

Based on the dimensions of interpersonal *communication* and the literature, Rubin and Martin constructed a 60-item questionnaire called Inter-

personal Communication Competence Scale [35]. They conducted a study with 477 students, analyzed the validity, and derived a short form consisting of ten Likert questions. Considering these ten items, we chose and translated five representative statements we found most suitable for our context with kind permission of the first author, namely statements 1, 4, 10, 19, and 28 [35, p. 39].

Schwarzer and Jerusalem have developed and optimized a questionnaire to measure *self-efficacy* for more than 20 years [36]. Based on this, Beierlein et al. developed the Self-Efficacy Scale Short Form, consisting of only three items, and compared it with the work of Schwarzer and Jerusalem in a study with more than 1000 subjects [37]. We evaluated both questionnaires and selected item 3 of the work of Beierlein et al. [37] and statements 1, 2, 5, 8, 9, and 10 of the work of Schwarzer and Jerusalem [36]. Beierlein and Jerusalem gave their friendly permission to use their questionnaires.

Kember et al. analyzed the literature on the nature of *reflective thinking* and developed an instrument comprising 16 Likert questions [38]. They conducted a study with 303 students and evaluated the reliability of the instrument. Based on the four statements addressing general reflective thinking, we found the statements 11 and 15 [38, p. 395] best applicable to our school context. We therefore decided to use these two statements and translated them into German with friendly permission of the first author.

Bierhoff et al. explored the meaning and measurement of *personal responsibility* and developed an 18-item questionnaire, which they used in three studies with 103, 120, and 85 participants respectively, confirming its validity and reliability [39]. We evaluated the 18 statements regarding their suitability for our context and selected the items 1, 2, 6, 7, 10, 14, 17, as well as 18 [39] and slightly adjusted the statements 1, 2, and 6 for their use in the context of schools. Bierhoff gave his friendly permission to use the questionnaire.

Satow designed a comprehensive assessment framework to estimate a person's Big Five personality traits and analyzed its validity as well as reliability based on more than 3000 responses [40]. With kind permission by Satow, we selected the items 1, 2, 4, 5, and 10 of the *openness* dimension as well as the *agreeableness* statements 1, 3, 6, 7, 9, and 10 [40] to be included in our SEPC.

Dalbert developed a stable scale to assess the *uncertainty tolerance* of a person and shared the results of her study with more than 1700 participants [41]. We used all eight statements of the German version in our personal competences questionnaire with friendly permission of the author.

To avoid subsequent statements with similar

wording, we presented the sub-questionnaires in the following order: CT–SE–PR–OP–CO–AG–UT–RE. We introduced a common 5-point rating scale for all statements, ranging from “agree”¹ (4) to “disagree” (0). We also asked students for suggestions for improvement to the department, and a reflection on their own potential for improvement. For the evaluation, we introduced eight overall scores, one for each factor, ranging from 0–100. The overall scores were calculated based on the mean of the equally weighted answers to the questions of the respective factor.

3.2 Validity

All measures were derived from the literature, which already ensured the validity of the respective instrument. However, since the questionnaires of the factors critical thinking, communication, and reflective thinking were translated from English into German by two of the authors, a re-assessment of the constructed questionnaires was necessary. Two different educators teaching the subject “social and personal competence” were chosen as experts to judge the validity of the translated questionnaires in the investigated context. They rated the suitability of the statements to measure the respective attribute on a Likert scale with the labels “highly relevant”, “quite relevant”, “somewhat relevant”, and “not relevant”, as described in the literature [42, 43]. The scale content validity index (S-CVI) was calculated by averaging the ratio of the number of statements rated as “quite relevant” or “highly relevant” to the total number of statements, resulting in an S-CVI of 0.86 for the critical thinking measure, 0.80 for the communication questionnaire, and 1.00 for reflective thinking. Since all three factors met the agreement threshold of 0.80 [42], no further adjustments were performed and the constructed measures are seen as valid.

3.3 Sample and Statistical Analysis

A description of the sample characteristics is shown in Table 1. The anonymous online survey was conducted in each cohort within a short period of time during class and closed immediately afterwards to prevent wrongfully submitted answers. The survey was conducted during the winter term 2018/2019 and answered by the students of grade 9, 10, and 11, encompassing 12 cohorts. We collected and analyzed the 312 responses of the 359 students, corresponding to an overall response rate of 87%.

The analysis has been carried out using a top-down approach in three steps: First, we performed a factor analysis using the minimum residual method

¹ The scales and questions have been translated from German.

Table 1. Sample Characteristics

Characteristic	LO 9 n (%)	TR 9 n (%)	LO 10 n (%)	TR 10 n (%)	LO 11 n (%)	TR 11 n (%)	Total n (%)
Gender							
Female	5 (7)	10 (14)	9 (20)	14 (21)	3 (6)	5 (9)	46 (13)
Male	66 (93)	61 (86)	37 (80)	53 (79)	44 (94)	52 (91)	313 (87)
Age							
14	37 (52)	49 (69)		1 (1)			87 (24)
15	23 (32)	17 (24)	31 (67)	34 (51)	2 (4)		107 (30)
16	9 (13)	5 (7)	13 (28)	19 (28)	24 (51)	18 (32)	88 (25)
17	2 (3)		2 (4)	11 (16)	16 (34)	23 (40)	54 (15)
18				2 (3)	3 (6)	12 (21)	17 (5)
19					2 (4)	4 (7)	6 (2)
Survey response							
Response	59 (83)	62 (87)	43 (93)	58 (87)	42 (89)	48 (84)	312 (87)
No response	12 (17)	9 (13)	3 (7)	9 (13)	5 (11)	9 (16)	47 (13)

Note. LO X: Learning office cohorts at grade X, TR X: traditional cohorts at grade X.

[44, 45] to explore how our measured factors interact with each other. Second, the reliability of the constructed questionnaire was evaluated by analyzing Cronbach's alpha [46] of each dimension separately. Finally, we searched for significant differences in the distribution of the eight total scores according to the used approach (learning office: LO, traditional: TR) as well as grade (9, 10, 11). Since the underlying data stem from a Likert scale, we performed non-parametric Kruskal-Wallis tests.

4. Results and Interpretation

4.1 Factor Analysis and Overall Influential Factors

We found an interesting suitable model using three factors. Their interactions with the original eight factors are shown in Table 2. The model was able to differentiate between the three derived factors quite clearly and assign most of the eight original dimensions to one principal factor; only personal responsibility and communication could be partly seen as a cross-cutting concern. As a result of an iterative

approach, we called the components describing our statistical model the “3R-factors”: “F1: reasonable efficacy”, “F2: reflective risk affinity”, and “F3: respectful interaction”.

Reasonable efficacy encompasses students' ability to reasonably and critically evaluate information in order to solve problems in a self-efficient way using their acquired competences. The discovered strong connection between self-efficacy and critical thinking is in accordance with findings of the literature [47, 48].

The second factor *reflective risk affinity* describes the learners' willingness to accept risks by being open to new and uncertain situations, but keeping their responsibility in mind and using reflective thinking to evaluate these situations first to assess the outcome. The composition of this factor is supported by the literature: Bierhoff et al. discovered a significant correlation between personal responsibility and a person's openness [39]. The intuitive linkage between openness and uncertainty tolerance has also been confirmed by the literature [49], while other studies examined the connection

Table 2. Factor Analysis of the SEPC (3R-Factors)

Original Factor	Factor Loading		
	F1: Reasonable Efficacy	F2: Reflective Risk Affinity	F3: Respectful Interaction
Self-efficacy	0.99	−0.01	−0.02
Critical thinking	0.59	0.10	0.08
Openness	−0.02	0.68	−0.09
Reflective thinking	−0.04	0.55	0.13
Personal responsibility	0.20	0.47	0.10
Uncertainty tolerance	0.08	0.26	−0.07
Agreeableness	−0.02	0.00	0.81
Communication	0.25	0.03	0.37

Note. N = 312. The factor analysis was carried out using the minimum residual method and an Oblimin rotation based on the Spearman correlations. Factor loadings higher than 0.25 are printed in **bold**.

Table 3. Reliability of SEPC Factors

Factor	Number of Questions	Cronbach's α
Critical thinking	7	0.83
Self-efficacy	7	0.85
Personal responsibility	8	0.40
Openness	5 (4)	0.56 (0.67)
Communication	5	0.61
Agreeableness	6	0.76
Uncertainty tolerance	8 (6)	0.57 (0.61)
Reflective thinking	2	0.72

Note. N = 312. Numbers in brackets refer to the respective values after dropping unreliable columns.

between reflective writing and dealing with uncertainty [50, 51].

Respectful interaction, the third derived factor, is regulated by students' communication skills and their agreeableness to achieve thoughtful social interaction. The intuitive relation between agreeableness and communication became apparent in several studies [52–54].

4.2 Reliability

The results of the reliability analysis of all eight factors are shown in Table 3. The intern consistencies of the factors critical thinking, communication, reflective thinking, self-efficacy, and agreeableness were acceptable from the start, while the Cronbach's alpha of the openness and uncertainty tolerance factors had to be improved by dropping one and two questions to an alpha value of 0.67 and 0.61 respectively, which is higher than the acceptable threshold of 0.6 [55]. Since all three of the dropped questions used an inverted scale, it seems that some of the students struggled with mentally inverting the scale to answer it correctly. We continued our analysis using only the reliable sets of questions to improve the reliability of our results; only the results of the factor personal responsibility should be treated with caution. The adaptation and the selection of questions to shorten the personal responsibility questionnaire may have decreased the reliability, or the formulation of the questions was not properly adjusted to the age group. Another reason could be that the measured factor influences in fact more than just one dimension.

4.3 Differences in 21st Century Skills

Fig. 1 gives an overview over all eight factors in the learning office (LO 9, N = 59) and traditional classrooms (TR 9, N = 62) at *grade 9*. The five-number summary is shown in Table 4. The biggest difference could be found in critical thinking: The distribution of the overall critical thinking score of learning office students was denser and rather

skewed to higher scores, while the data of traditional classrooms were wider-spread and shifted towards lower scores. However, a Kruskal-Wallis test found the difference not significant with a result of $p = 0.0588$.

This suggests that students who register for school have the same basis to start from; no indication of a selection bias between students choosing one of the approaches was observable. This corresponds to previous findings that in the first school year, learning office students appear to be struggling with the granted freedom [11]: They still have to acquire those personal competences before getting used to the new self-driven approach.

The observed distributions of the eight factors in the learning office (N = 43) and traditional classrooms (N = 58) at *grade 10* can be seen in Fig. 2 as well as Table 5. We were able to identify several interesting differences. First, the median rating of learning office students on the critical thinking scale was higher by an absolute value of about 9, which was significant in a Kruskal-Wallis test with $p = 0.0370$. Second, we found a highly significant difference in the self-efficacy dimension: The median rating of learning office students was higher by 7 points than in the traditional approach with $p = 0.0085$. Third, the personal responsibility factor

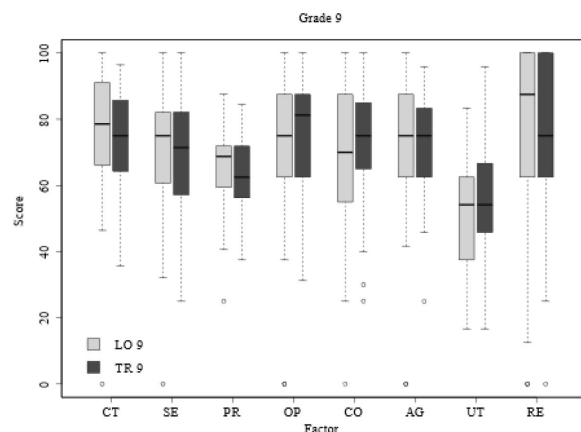
**Fig. 1.** Box Plot of SEPC Factors at Grade 9.

Table 4. Summary of SEPC Factors at Grade 9

Factor	Approach	Min.	Q1	Med.	Q3	Max.
Critical thinking	LO 9	0	66	79	91	100
	TR 9	36	64	75	85	96
Self-efficacy	LO 9	0	61	75	82	100
	TR 9	25	57	71	82	100
Personal responsibility	LO 9	25	59	69	72	88
	TR 9	38	56	62	72	84
Openness	LO 9	0	62	75	88	100
	TR 9	31	64	81	88	100
Communication	LO 9	0	55	70	88	100
	TR 9	25	65	75	85	100
Agreeableness	LO 9	0	62	75	88	100
	TR 9	25	62	75	83	96
Uncertainty tolerance	LO 9	17	38	54	62	83
	TR 9	17	46	54	67	96
Reflective thinking	LO 9	0	62	88	100	100
	TR 9	0	62	75	97	100

Note. LO 9: Learning office approach at grade 9 (N = 59), TR 9: Traditional approach at grade 9 (N = 62).

was rated significantly different with $p = 0.0491$ and a higher rating in the learning office with a shift of 7 points; however, this result should be treated with care due to the rather unreliable consistency of this factor. Finally, the openness dimension revealed another significant difference with $p = 0.0330$: The score of learning office students was higher with an absolute shift of 6 points. Communication, agreeableness, uncertainty tolerance, and reflective thinking did not reveal significant differences.

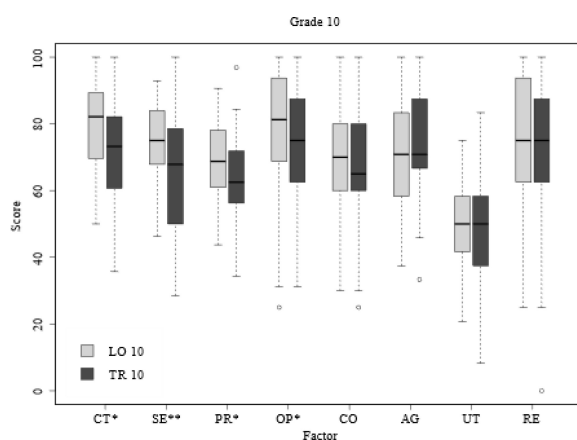
These findings suggest that students become more confident in their personal competences after one school year in the learning office, while their peers taught in the traditional way stay at about the same level. Since learning office students are required to use these competences to succeed while students in traditional classes are more driven and instructed by their teachers, this result supports

our belief that the learning office fosters the development of 21st century skills.

Fig. 3 and Table 6 show the ratings of learning office students (N = 42) and students of the traditional approach (N = 48) at *grade 11*. Interestingly, the learning office cohorts who have been used to the self-driven approach the longest rated themselves notably less confidently regarding their personal competences than the cohort in their second year. One difference was found significant: Learning office students reported a lower overall median agreeableness score of 12 points, which was found highly significant estimated by a Kruskal-Wallis test returning $p = 0.0015$.

The significantly lower agreeableness score could originate from the fact that learning office students are actually required to disagree with teachers and maybe even each other. This especially applies to the grade 11 students, since they were the very first two cohorts experiencing the new approach. They were the first to test completely new courses and material, which is why they are needed to disagree with their teachers to improve the approach itself. Using a learner-centered approach, they were included in the development of the new learning office approach ever since by being regularly invited to conferences and being given the chance to provide feedback and pass criticism, possibly resulting in a lower agreeableness score. Furthermore, the agreeableness factor itself could be in conflict with other factors: Thinking critically, questioning, and challenging could negatively influence the agreeableness score.

As for the other factors, multiple interpretations of the lower ratings of the learning office students exist. First, the first learning office cohorts may be



* $p < 0.05$. ** $p < 0.01$

Fig. 2. Box Plot of SEPC Factors at Grade 10.

Table 5. Summary of SEPC Factors at Grade 10

Factor	Approach	Min.	Q1	Med.	Q3	Max.
Critical thinking*	LO 10	50	70	82	89	100
	TR 10	36	61	73	82	100
Self-efficacy**	LO 10	46	68	75	84	93
	TR 10	29	51	68	79	100
Personal responsibility*	LO 10	44	61	69	78	91
	TR 10	34	56	62	72	97
Openness*	LO 10	25	69	81	94	100
	TR 10	31	62	75	88	100
Communication	LO 10	30	60	70	80	100
	TR 10	25	60	65	80	100
Agreeableness	LO 10	38	58	71	83	100
	TR 10	33	67	71	86	100
Uncertainty tolerance	LO 10	21	42	50	58	75
	TR 10	8	38	50	58	83
Reflective thinking	LO 10	25	62	75	94	100
	TR 10	0	62	75	88	100

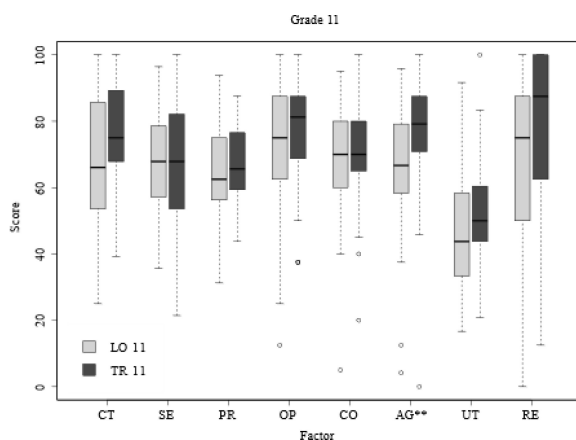
Note. LO 10: Learning office approach at grade 10 (N = 43), TR 10: Traditional approach at grade 10 (N = 58). * $p < 0.05$. ** $p < 0.01$.

an outlier – not only because of their inclusion in the development of the new approach, but also due to a selection bias: Students who are the first to decide to take part in such an experiment having a tremendous impact on their future life may have different characteristics than other students. Second, learning office students closely work together with teachers, which could provide them additional insight into their own potential for improvement. Third, the lower ratings could be in turn a result of their improved personal competences and increased self-awareness: They know what they do not know, which might be the reason they are less confident in their own skills.

A strong indication supporting this thesis could be found in the written reflections provided by students. The last question of the survey asked students to reflect on themselves (“I see the follow-

ing potential to improve myself:”). We categorized the written reflections using two groups:

- (1) *Meaningful reflection*: The student identified what they could improve to succeed in the future. Exemplary answers of students categorized as meaningful reflection were “study more”, “start earlier with the work”, “participate more”, “invest more time”, and “be more ambitious and less lazy.”
- (2) *No meaningful reflection*: The student did not provide any text or the text did not qualify as a meaningful reflection. Reflections we did not categorize as meaningful were funny comments and texts blaming the school or teachers. Since we gave students the possibility to provide written feedback and pass criticism in the directly preceding question, we did not see these comments as a meaningful reflection on how they can improve themselves. Examples of this category were “less social life”, “I would be more motivated if class was more interesting”, and “I am perfect.”



** $p < 0.01$

Fig. 3. Box Plot of SEPC Factors at Grade 11.

Table 7 shows the number of meaningful reflections provided by students of the learning office and traditional classrooms at all three grades as well as the p-value returned by a chi square test. Grade 9 revealed no significant differences regarding the number of meaningful reflections, which is another indication that there is no selection bias in the current students admitted to school. However, a notable increase in the number of meaningful reflections in the learning office approach could be observed at higher grades: While the percentage of meaningful reflections rose to 84% and 88% at

Table 6. Summary of SEPC Factors at Grade 11

Factor	Approach	Min.	Q1	Med.	Q3	Max.
Critical thinking	LO 11	25	54	66	85	100
	TR 11	39	68	75	89	100
Self-efficacy	LO 11	36	57	68	79	96
	TR 11	21	54	68	82	100
Personal responsibility	LO 11	31	56	62	75	94
	TR 11	44	59	66	76	88
Openness	LO 11	12	62	75	88	100
	TR 11	38	69	81	88	100
Communication	LO 11	5	60	70	80	95
	TR 11	20	65	70	80	100
Agreeableness**	LO 11	4	59	67	79	96
	TR 11	0	71	79	88	100
Uncertainty tolerance	LO 11	17	33	44	58	92
	TR 11	21	45	50	59	100
Reflective thinking	LO 11	0	53	75	88	100
	TR 11	12	62	88	100	100

Note. LO 11: Learning office approach at grade 11 (N = 42), TR 11: Traditional approach at grade 11 (N = 48). ** $p < 0.01$.

Table 7. Meaningful Written Reflections Provided by Students

Grade	Learning Office	Traditional Approach	p
9	37 of 59 (63%)	39 of 62 (63%)	0.9826
10	36 of 43 (84%)	37 of 58 (64%)	0.0270
11	37 of 42 (88%)	28 of 48 (58%)	0.0017

Note. The reported p-values were returned by a chi square test.

grade 10 and 11, the number of meaningful reflections stayed the same at the 10th grade with 64% and even dropped to 58% at grade 11 in the traditional approach. A chi square test found the difference significant at grade 10 and highly significant at grade 11. These findings show that the learning office seems to provide an environment which nurtures reflective thinking.

Table 8 summarizes the means and standard deviations of all factors and statements grouped by grade and approach. Although the underlying data are ordinal and our statistical methods were selected accordingly, we decided to report the mean and standard deviation rather than the median value and interquartile range. The reason for this lies in the detailed items: Since we used a five-point Likert scale, most median values are 3 (64%) and 2 (18%), not allowing for a nuanced overview.

5. Discussion

5.1 Findings

Our answers to the posed research questions are as follows:

RQ 1: How can 21st century skills be feasibly estimated using a self-report research instrument?

We conducted an extensive review of the litera-

ture and identified several ways to assess 21st century skills. Based on the literature as well as existing validation studies of established questionnaires, we constructed the self-evaluation of personal competences (SEPC) questionnaire aiming to estimate eight selected factors. The questionnaire should be suitable for teenagers and answerable within 15 minutes, which is why we needed to shorten some of the established questionnaires of the literature.

RQ 2: Which statistical model lends itself to describing the estimated 21st century skills?

Based on the 312 responses to our SEPC questionnaire, we were able to derive an interesting statistical model using a minimum residual factor analysis. The eight dimensions could be approximated using three factors we called the “3R-factors”: reasonable efficacy, reflective risk affinity, and respectful interaction.

Is the constructed research instrument valid and reliable?

RQ 3: Since all measures are based on established questionnaires of the literature, the *validity* of the assessment tools has already been confirmed. The questionnaires which were translated from English to German were judged by two experts and rated with an S-CVI of at least 0.8, confirming their validity. Except for personal responsibility, all factors revealed an acceptable level of *reliability* with a Cronbach’s alpha of at least 0.60 after we excluded three questions.

RQ 4: Do students taught in the learning office report different levels of 21st century skills compared to students in traditional classes?

We found several interesting differences between learning office students and students of traditional

Table 8. Means and Standard Deviations of All Factors and Items by Approach and Grade

	LO 9 M (SD)	TR 9 M (SD)	LO 10 M (SD)	TR 10 M (SD)	LO 11 M (SD)	TR 11 M (SD)	Total M (SD)
Critical thinking	76.45 (18.04)	71.77 (15.38)	79.49 (13.04)	73.09 (16.18)	68.2 (18.41)	75.37 (15.6)	74.04 (16.46)
CT item 1	3.22 (0.87)	3.03 (0.83)	3.33 (0.71)	3.03 (0.72)	2.93 (1)	3.23 (0.86)	3.13 (0.84)
CT item 2	2.98 (0.92)	2.84 (0.89)	3.14 (0.74)	3.09 (0.8)	2.76 (0.96)	3.02 (0.86)	2.97 (0.87)
CT item 3	3.31 (0.84)	2.89 (0.94)	3.35 (0.65)	3.07 (0.79)	2.88 (0.94)	3.02 (0.81)	3.08 (0.85)
CT item 4	3.1 (1.01)	2.94 (0.94)	3.07 (0.88)	2.83 (1.09)	2.93 (0.95)	3.04 (0.82)	2.98 (0.96)
CT item 5	2.86 (1.24)	2.95 (0.86)	3.21 (0.77)	2.86 (1.02)	2.38 (1.13)	2.98 (0.86)	2.88 (1.02)
CT item 6	3.07 (1)	2.84 (1.01)	3.21 (0.8)	2.86 (1.03)	2.69 (1.12)	3.04 (0.87)	2.95 (0.99)
CT item 7	2.86 (0.97)	2.61 (1.14)	2.95 (0.95)	2.72 (0.97)	2.52 (1.04)	2.77 (1.17)	2.74 (1.05)
Self-efficacy	70.1 (18.54)	67.57 (16.57)	74.34 (11.77)	65.15 (18.24)	67.86 (17.92)	67.26 (19.16)	68.52 (17.41)
SE item 1	3.19 (0.88)	3.02 (0.98)	3.21 (0.77)	3 (0.9)	3.1 (0.91)	2.96 (0.92)	3.07 (0.9)
SE item 2	2.8 (0.89)	2.82 (0.82)	2.95 (0.79)	2.72 (0.77)	2.71 (0.86)	2.52 (0.92)	2.76 (0.84)
SE item 3	2.8 (1)	2.6 (1)	2.95 (0.82)	2.52 (0.96)	2.5 (1.02)	2.44 (1.13)	2.63 (1)
SE item 4	2.81 (1.01)	2.84 (0.83)	3.05 (0.75)	2.64 (1.07)	2.69 (1.12)	2.88 (0.91)	2.81 (0.96)
SE item 5	2.63 (0.96)	2.53 (0.97)	2.86 (0.86)	2.47 (1.19)	2.62 (0.99)	2.83 (1.02)	2.64 (1.01)
SE item 6	2.61 (1.08)	2.6 (1.03)	2.77 (0.92)	2.33 (1.02)	2.48 (1.19)	2.6 (0.89)	2.56 (1.03)
SE item 7	2.8 (0.89)	2.52 (0.95)	3.02 (0.64)	2.57 (1.01)	2.9 (0.85)	2.6 (1.03)	2.71 (0.92)
Personal responsibility	65.1 (11.94)	64.06 (11.17)	67.81 (11.36)	63.09 (12.52)	65.33 (13.73)	68.03 (11)	65.37 (11.98)
PR item 1	2.61 (1.22)	2.66 (0.92)	2.65 (1.04)	2.69 (1.06)	2.9 (1.05)	2.83 (1.14)	2.71 (1.07)
PR item 2	2.24 (1.18)	2.18 (1.21)	2.26 (0.88)	2.29 (1.09)	2.02 (1.09)	2.33 (1.1)	2.22 (1.1)
PR item 3	2.47 (1.13)	2.39 (1.21)	2.63 (1)	2.45 (1.13)	2.81 (1.06)	2.58 (1.09)	2.54 (1.11)
PR item 4	2.83 (1)	2.77 (0.98)	2.72 (1.01)	2.57 (1.09)	2.64 (1.14)	3.1 (0.88)	2.77 (1.03)
PR item 5	3.27 (1)	3.37 (0.83)	3.51 (0.74)	3.12 (0.84)	3.26 (0.94)	3.46 (0.77)	3.32 (0.86)
PR item 6 (–)	2.61 (1.2)	2.08 (1.38)	2.6 (1.18)	2.07 (1.36)	2.19 (1.4)	2.35 (1.31)	2.31 (1.32)
PR item 7	2.24 (1.01)	2.76 (1.07)	2.7 (1.06)	2.6 (0.99)	2.52 (1.13)	2.81 (1)	2.6 (1.05)
PR item 8 (–)	2.56 (1.19)	2.29 (1.09)	2.63 (1.05)	2.4 (1.14)	2.55 (1.15)	2.29 (1.13)	2.44 (1.13)
Openness	73.09 (21.47)	75.4 (17.38)	79.94 (17.65)	72.63 (18.36)	72.02 (20.35)	76.95 (15.04)	74.86 (18.57)
OP item 1	3.07 (1.03)	3.02 (0.91)	3.26 (0.76)	2.72 (1.06)	2.83 (1.03)	2.94 (0.89)	2.97 (0.97)
OP item 2	3.22 (0.97)	3.34 (0.89)	3.44 (0.85)	3.02 (1.03)	3.14 (1)	3.21 (0.85)	3.22 (0.94)
OP item 3 (–)	1.81 (1.11)	2.33 (0.94)	2.29 (1.15)	1.63 (1.26)	1.78 (1.26)	2.06 (1.14)	1.94 (1.18)
OP item 4	2.56 (1.28)	2.82 (1.22)	3.16 (1.04)	2.9 (1.29)	2.69 (1.42)	3.06 (0.84)	2.85 (1.21)
OP item 5	2.85 (1.19)	2.89 (1.22)	2.93 (1.03)	2.98 (1)	2.86 (1)	3.1 (0.9)	2.93 (1.07)
Communication	69.32 (20.03)	73.55 (17)	69.42 (16.41)	66.03 (17.06)	68.1 (16.75)	70.73 (14.87)	69.62 (17.25)
CO item 1	3.25 (0.98)	3.31 (1)	3.19 (0.88)	3.03 (1.12)	3.02 (1.26)	3.25 (0.91)	3.18 (1.03)
CO item 2	2.93 (1.1)	2.92 (0.96)	3.21 (0.89)	2.81 (1.07)	2.88 (1.06)	3.06 (1)	2.96 (1.02)
CO item 3	2.56 (1.26)	2.98 (0.97)	2.6 (1.05)	2.83 (1.01)	3.05 (1.19)	2.75 (0.96)	2.79 (1.08)
CO item 4	2.63 (1.24)	2.66 (1.27)	2.42 (1.26)	2.09 (1.41)	2.5 (1.25)	2.4 (1.22)	2.45 (1.28)
CO item 5	2.49 (1.14)	2.84 (1.09)	2.47 (0.93)	2.45 (1.05)	2.17 (1.17)	2.69 (1.06)	2.54 (1.09)
Agreeableness	72.32 (20.63)	72.98 (15.35)	71.51 (16.29)	74.43 (14.27)	66.37 (19.51)	77.34 (16.84)	72.7 (17.36)
AG item 1	3.15 (1.06)	3.05 (0.98)	2.93 (0.99)	3.19 (0.91)	2.76 (1.27)	3.29 (0.85)	3.08 (1.01)
AG item 2	2.98 (1.06)	3.02 (0.95)	2.79 (1.08)	3.09 (0.86)	2.64 (1.3)	3.13 (1.02)	2.96 (1.04)
AG item 3	3.46 (0.93)	3.56 (0.64)	3.47 (0.67)	3.64 (0.55)	3.33 (0.98)	3.67 (0.78)	3.53 (0.77)
AG item 4	2.12 (1.26)	2.37 (1.18)	2.19 (1.2)	2.34 (1.22)	2 (1.15)	2.52 (1.15)	2.27 (1.2)
AG item 5	2.81 (1.25)	2.82 (1.06)	2.98 (0.91)	2.79 (1.17)	2.74 (1.21)	3.21 (0.97)	2.88 (1.11)
AG item 6	2.83 (0.99)	2.69 (1)	2.81 (0.79)	2.81 (0.96)	2.45 (1.17)	2.75 (1)	2.73 (0.99)
Uncertainty tolerance	50.42 (17.5)	55.65 (16.48)	49.71 (12.58)	49.35 (16.29)	45.83 (17.09)	51.04 (15.53)	50.64 (16.25)
UT item 1	2.97 (1.05)	2.98 (0.93)	2.98 (0.8)	2.5 (1.01)	3.12 (0.94)	2.79 (0.97)	2.88 (0.97)
UT item 2 (–)	2.2 (1.19)	1.93 (1.2)	1.9 (1.16)	1.79 (1.12)	1.59 (1.06)	1.85 (0.97)	1.88 (1.13)
UT item 3	1.97 (1.34)	2.32 (1.21)	2.07 (1.06)	2.31 (1.22)	1.69 (1.22)	1.94 (1.26)	2.07 (1.24)
UT item 4	2.46 (1.13)	2.5 (1.02)	2.42 (1.01)	2.45 (1.03)	2.36 (1.06)	2.29 (1.11)	2.42 (1.05)
UT item 5 (–)	1.2 (1.11)	1.37 (1.05)	0.83 (0.88)	1 (0.91)	1.03 (0.84)	1.08 (1.01)	1.09 (0.97)
UT item 6	2.46 (1.26)	2.92 (1)	2.33 (1.04)	2.47 (1.16)	1.83 (1.19)	2.71 (1.15)	2.49 (1.17)
UT item 7	1.42 (1.18)	1.73 (1.16)	1.21 (1.01)	1.33 (1.22)	1.31 (1.42)	1.58 (1.15)	1.45 (1.2)
UT item 8 (–)	0.83 (1)	0.9 (1.04)	0.93 (0.88)	0.79 (0.97)	0.69 (1.18)	0.94 (1.06)	0.85 (1.02)
Reflective thinking	74.58 (25.1)	75.6 (22.23)	76.45 (20.08)	72.84 (22.84)	72.32 (25.98)	77.86 (22.07)	74.92 (23.03)
RE item 1	3.17 (1.04)	3 (1.09)	3.26 (0.85)	3.03 (1.08)	3.12 (1.13)	3.19 (0.98)	3.12 (1.03)
RE item 2	2.8 (1.2)	3.05 (0.93)	2.86 (0.94)	2.79 (0.99)	2.67 (1.22)	3.04 (1.01)	2.88 (1.05)

Note. LO X: Learning office cohorts at grade X, TR X: traditional cohorts at grade X. The statements were presented in German. Items in cursive writing were removed from the calculations due to their unreliability. The means were calculated using a mapping from “agree” (4) to “disagree” (0). The reported scores of negatively worded statements have been inverted (higher scores indicate lower agreement to the statement). The overall factors comprise the equally weighted average of its subitems scaled to a range from 1–100.

classrooms. In their first school year at the IT department, our students reported no notable differences in the overall scores for the eight estimated factors at grade 9. This is an indication that students who registered for school had the same starting point; no hints of a selection bias could be observed.

At grade 10, we were able to identify several significant differences in the reported overall factors of the estimated 21st century skills: Learning office students rated themselves significantly better in the factors self-efficacy, critical thinking, openness, and personal responsibility. This suggests that students grow more confident in their 21st century skills in a learning office setting after completing one school year compared to their peers of traditional cohorts.

This effect was not observable at grade 11. Students reported to be significantly less agreeable in the learning office, which could be in turn a result of their inclusion in the development of the approach itself. Another interpretation can be found in their increased self-awareness. An indication supporting this hypothesis could be found in the reflective thinking factor: Although the median reflective thinking score was notably lower in the learning office at the 11th grade, they wrote significantly more meaningful reflections, which we see as a strong indication of improved reflective thinking.

5.2 Notes and Limitations

There are certain limitations of this study we are aware of [2, 3, 6, 11]. First, the learning office approach is subject to bias: Random group assignment is not practicable and ethical. However, we found no hints of such a selection bias in this study. Second, due to the nature of the study design as well as the small sample size, we are only able to assess statistical associations and not causality. Third, there may be additional variables besides the chosen approach which could have had influence on the measured differences, like the class teachers and classrooms. Since this is a study in the field of education, we are required to conform to given restrictions and work with them. Finally, although the constructed SEPC questionnaire is based on well-established research instruments, a bias could have been introduced by the selection of only a subset of the statements.

As the students were asked to answer personal questions giving insight into their self-perception

and personality, several precautions were taken to protect them from any harm that may arise. The survey was conducted in a strictly anonymous way. Neither their teachers nor the authors knew an individual's answer at any point. In addition, answering the survey was voluntary. Furthermore, students that register for the IT department are aware of their inclusion in a scientific study that has been authorized by the Federal Ministry of Education.

6. Conclusions

Due to the found strong indications, we conclude that the learning office approach indeed fosters students' acquisition of 21st century skills and that learning office students acquire additional 21st century skills compared to their traditional peers with respect to their self-efficacy, ability to think critically, openness, and reflective thinking. Since we found that learning office students perform equally well after the first year, the acquisition of 21st century competences are an additional benefit for our students. Given the findings of this study and the increasing importance of 21st century skills, we believe that the proposed approach makes a major contribution to engineering education and prepares students for a successful course of study at university level.

Future work includes further investigations and follow-up studies in this area. Our self-reported approach could be complemented with additional sources of information, like parent report and observation. Furthermore, the experiment could be repeated using the same SEPC questionnaire to investigate whether the first learning office cohorts were an actual outlier. In the long term, interviewing graduates who are willing to share their experiences and give insight into their careers would be another interesting possibility to reevaluate the approach aiming to foster graduates' 21st century skills and capacity to deal with problems in real life.

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