

Insights into STEM Education Praxis: An Assessment Scheme for Course Syllabi

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Abstract

Post-secondary institutions within the European Higher Education Area have been adapting quality assurance mechanisms for course design, delivery, and evaluation following a learner-centered approach. The purpose of this exploratory study was to delineate the teaching practices in science, technology, engineering, and mathematics at the postsecondary level through an assessment of course syllabi. An analytical rubric was developed with the STEM community, STEM education, and STEM assessment factors in order to assess teaching practices through syllabi of the courses offered at a public university within the European Higher Education Area. Data were analyzed at the item level using a Mann-Whitney non-parametric test and at the factor level with an independent t-test. Results showed that there were statistically significant differences between the externally accredited and non-accredited programs in STEM_education and STEM_assessment variables ($p < 0.01$), which indicated a practical significance in favor of accredited programs. There was reason to believe that the external accreditation process has a positive impact on instructors in encouraging them to align their syllabi with the STEM education praxis under the influence of the student-centered teaching and learning paradigm.

Key Words

Accreditation, Bologna Process, European Higher Education Area, STEM Education, Syllabi.

The changing expectations of 21st century economies from post-secondary education institutions are reinforced by broader influences, including the increased demand for a workforce equipped with a capacity to innovate. Innovation is a highly interactive process tightly connected to life and which fosters communication, interdisciplinary thinking, and team-building skills (Organisation for Economic Co-operation and Development [OECD], 2010a). Innovation necessitates the integration of diverse science, technology, engineering, and mathematics (STEM) knowledge, skills, and values that transcend disciplines (National Research Council, 2011; OECD, 2010b). From this perspective, the STEM education praxis is defined as a set of learner-centered practices focusing on developing innovation literacy skills within the education of STEM subjects (Corlu,

2012). The changing expectations of the 21st century economies demand the education of STEM subjects to foster interdisciplinary knowledge, skills, and values that are relevant to real life.

Post-secondary institutions within the European Higher Education Area (EHEA) are making a commitment to promote life-long learning. Aligned with the goals set by the European Commission, STEM departments at European universities are also endeavoring to meet Bologna Process standards by focusing on learners: How learners might be educated to become highly skilled, engaged, and self-regulated innovators and how such skills should be assessed (European Commission, 2012). Post-secondary institutions within the EHEA are currently adapting quality assurance mechanisms for course design, delivery, and evaluation with a learner-centered approach.

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Quality assurance in course design, delivery, and evaluation begins parallel with instructors' first contact with students. A syllabus provides faculty members at STEM departments with a capstone opportunity to encourage and guide their students to become innovators (Grunert O'Brien, Millis, & Cohen, 2008). However, there is a need to investigate whether syllabi of STEM courses offered at EHEA universities are aligned with the STEM education praxis (Kalayci, 2009). Thus, the primary purpose of the current study is to develop a comprehensive STEM syllabus assessment scheme in alignment with the higher education quality assurance mechanisms used in Europe and the United States. Second, the study aims to delineate STEM teaching practices at an EHEA university through an assessment of the course syllabi. As a broader impact, this study contributes to the international efforts in developing standards for course design, delivery, and evaluation at the post-secondary level.

Specifically, the researcher seeks answers to:

- 1) How can STEM teaching practices be outlined through an analytical assessment of course syllabi?
- 2) Are the syllabi of courses offered at STEM departments accredited by an external body more aligned with the STEM education praxis than the syllabi of courses offered at STEM departments that are not externally accredited?

Perspectives

Quality Assurance for the Education of STEM: One of the most popular quality assurance mechanisms in the education of STEM disciplines was established by the Accreditation Board for Engineering and Technology (ABET). The U.S.-based ABET has been influential throughout the world in assuring quality and in stimulating innovation in the education of STEM disciplines (ABET, 2011a, 2011b, 2011c, 2011d). The programs, which have received accreditation by ABET, require the utilization of science, technology, and mathematics alongside engineering concepts as a foundation for discipline-specific practice, which includes the recognition, prevention, and solution of problems critical to real life (ABET, 2011e). Standards set by ABET have earned a reputation of being concerned with the global variables that governed the outcomes of the programs (Milem, Berger, & Dey, 2000). This withstanding, ABET standards have attained a certain degree of world-wide popularity due to the simplicity and flexibility of the accreditation process.

ABET standards have also gained, to a certain extent, popularity among universities outside of the United States. Specifically, several EHEA universities have sought accreditation, for which they had to meet the standards similar to those used to evaluate their counterparts in the United States (ABET, 2011e). Along with ABET accreditation, EHEA universities were obliged to raise their standards for accreditation by implementing the quality assurance system currently under development by the Bologna Process (Moon & Duran, 2008). The ABET accreditation standards have guided some EHEA universities to better prepare for the Bologna Process.

The Bologna Process was initiated by the European Commission with the aim of ensuring congruency in the standards and quality of higher education in the EHEA, including post-secondary institutions in Turkey. Some of the priorities of the Bologna Process were to raise standards in life-long learning, employability, and student-centered learning while simultaneously increasing the innovation capacities of students studying at EHEA universities (Eurydice Network, 2012). Turkish higher education institutions have experienced challenges similar to those encountered by their counterparts in other EHEA universities, including the lack of an efficient internal quality assurance system or a well-articulated self-assessment procedure to improve the effectiveness of instructional quality (Kalayci, 2009). Turkish higher education institutions have particularly struggled to meet the Bologna Process standards for instructional quality, research, and academic freedom (Turkish Academy of Sciences, 2010). The Bologna Process has, thus, introduced a number of serious challenges to Turkish universities, which has consequently elicited the need to shift from the traditional instruction-centered paradigm to a learner-centered one.

The Learning-Centered Syllabus: Several researchers have examined the structural and functional multiplicities with regard to purpose and content of a syllabus. Based on their own personal experience, some scholars have identified four major uses of a syllabus: (1) a contract between the instructor and the students, (2) a communication device that would connect the instructor to the students, (3) an instructional plan for the instructor, and (3) a cognitive map for the students (Matejka & Kurke, 1994). Other researchers have focused on accountability, emphasizing the use of the syllabus as an administrative tool for the documentation of teaching effectiveness, which could therefore provide evidence for the accreditation of an institution or

the performance evaluation of its instructors (Bers, Davis, & Taylor, 1996). Related to this perspective, Cullen and Harris (2009) claimed that the syllabus might gauge the mindset of the instructor, assessing whether the instructor was influenced by an instructional or a learner-centered paradigm. The second set of multiplicities concerned itself with content tightly connected to the purpose of the syllabus. One notable exception to the conventional syllabus design, which included course objectives, calendar, and grading, was the learner-centered model (Grunert, 1997). In the learner-centered model, the content of a conventional syllabus was extended to include learning tools that would help students succeed in the course in addition to a variety of mechanisms that would encourage student engagement in the course and interaction both with the instructor and among themselves (Grunert O'Brien et al., 2008). In this model, the syllabus was an instructional aide and a motivational tool that would extend learning beyond the physical borders of a classroom and continue after the end of the class (Parkes & Harris, 2002). Several researchers have thence eschewed the idea that the syllabus is only to be used as a course outline.

Method

Rubric for Assessment of STEM Teaching Practices through Course Syllabi

Given the need to develop a usable framework for assessing STEM teaching through course syllabi, an analytical rubric was developed for the current study (see Appendix 1). A critical review of the previous studies on STEM education praxis, teaching, quality assurance systems, syllabus design models, and corresponding assessment rubrics (cf. Cullen & Harris, 2009) resulted in the establishment of three major categories: the STEM community, STEM integration, and STEM assessment. The first category examined the STEM community as creating a sense of community is a critical feature within STEM education, requiring a connectedness between student and instructor, as well as among students (Froyd & Ohland, 2005; McKenna, Yalvac, & Light, 2009). Such a connectedness was based on students' and instructors' previous experiences or interests in diverse STEM fields (Corlu, 2012). The second category examined STEM integration with respect to in-depth knowledge, skills, and values, in addition to whether the syllabus displayed any evidence that life-long learning and the interdisciplinary nature of STEM education were to be fostered during the course (Borrego,

Froyd, & Hall, 2010). Finally, the third category focused on STEM assessment, such as authentic assessment and self-regulation, in addition to more conventional formative and summative assessment tasks (Capraro & Corlu, 2013).

Data Sources

STEM teaching practices were assessed through the syllabi of the courses offered at a highly popular state university in Turkey, which specifically described its courses as STEM or non-STEM. The university was one of the five higher education institutions in Turkey accredited by ABET. Data were collected during the six-week-long summer term in 2012. Summer school was considered an intensive third term at this English medium-of-instruction university requiring the same amount of contact hours in total as either the Fall or Spring terms. The university was similar to a 4-year doctoral/research university in the United States in terms of organization, awarding bachelor's, master's, and doctorate degrees, as well as in terms of the intensity of research activity of the instructors. Among its five colleges, only the programs at the college of engineering were externally evaluated and which have been accredited by ABET for more than five years. No information was available for public access regarding the progress achieved for accreditation by the Bologna Process. The university did not provide instructors with any instructional support or training on how to prepare a learner-centered syllabus.

The syllabi came from courses categorized as STEM by the university administration, all of which were publicly available through the university's website. Descriptions of all 200 plus courses offered during summer school were thoroughly read by the researcher in order to ensure that there was no other course that could be categorized as STEM. After a careful examination of the titles and descriptions, the courses were further categorized into individual STEM categories (see Table 1). A senior faculty member of the university holding administrative responsibility was consulted to triangulate the distribution of courses into separate STEM areas. As a result, among the 93 courses in the initial list, eight were considered as non-STEM (teacher education courses). Not all courses in the initial list offered a syllabus. Thus, $N = 57$ syllabi (excluding the syllabi jointly used by instructors who were teaching different sections of the same course or courses without syllabi) were included in the sample.

Table 1.
Distribution of Courses for Each STEM Category

		Science	Technology	Engineering	Mathematics	Total
Non-accredited Program	No syllabus	20	1	0	1	22
	With syllabus	19	2	0	13	34
	Total	39	3	0	14	56
Externally accredited Program	No syllabus	0	0	6	0	6
	With syllabus	0	0	23	0	23
	Total	0	0	29	0	29
Total	No syllabus	20	1	6	1	28
	With syllabus	19	2	23	13	57
	Total	39	3	29	14	85

The analytical approach to rubric-based assessment required the examination of each syllabus by elaborating on several items at different ordinal levels (Gronlund, 1998; Wright, 2008). The analytical rubric used in the current study consisted of 15 items, which were theoretically grouped under three main factors. Ordinal levels were used to assign a minimum value of 1 (no evidence for STEM education praxis) and a maximum value of 4 (complete alignment with STEM education praxis) for each syllabus. Item 1 and item 12 were excluded from the analysis due to their low corrected item total correlation (Pallant, 2001). Next, three independent continuous variables were formed by calculating the mean of the respective observed ordinal variables. Internal consistency of the scores was estimated by Cronbach's *alpha*. The reliability estimates for *STEM_integration* ($\alpha = 0.81$) and *STEM_assessment* ($\alpha = 0.64$) factors were at acceptable levels for an exploratory study (Hair, Anderson, Tatham, & Black, 1995). The results obtained concerning the *STEM_community* ($\alpha = 0.36$) factor should be interpreted with caution. Two external experts on STEM and course syllabi design evaluated the rubric to support content validity based on the scores. The estimates of score reliability indicated a promising measure for future development of the instrument with an upper limit of 0.61 (*STEM_community*), 0.90 (*STEM_integration*), and 0.81 (*STEM_assessment*) for evidence of validity (Angoff, 1988).

Data Analyses

The study employed descriptive statistical methods to draw an outline of STEM teaching practices through an assessment of course syllabi. Data were inspected for normality and outliers and then analyzed at the item level using the Mann-Whitney non-parametric test with Stata 12SE. An independent *t*-test was conducted using PASW18 to answer the second

research question. Effect sizes were estimated in score-world statistics with Cohen's *d*. A post-hoc power analysis was conducted with G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007).

Results

Table 2 presents the descriptive statistics, including the median, mode, and extreme scores for the ordinal variables.

The non-parametric two-sample Wilcoxon rank-sum (Mann-Whitney) test showed that the sums of syllabi from externally accredited program course ranks were statistically significantly higher for item 6 ($z = -2.42$; $p < 0.05$; $r = z/\sqrt{n} = 0.32$; Cohen's $d = 0.68$), item 8 ($z = -3.18$; $p < 0.01$; $d = 0.93$), item 9 ($z = -2.34$; $p < 0.05$; $d = 0.65$), item 10 ($z = -2.48$; $p < 0.05$; $d = 0.70$), item 11 ($z = -2.11$; $p < 0.05$; $d = 0.58$), and item 14 ($z = -5.44$; $p < 0.05$; $d = 2.08$). The large effect sizes for item 8 and item 14 designated that noteworthy differences existed between the groups in terms of the emphases given for skills and authentic assessment tasks in the course syllabi. It was noteworthy that the range for some items was very narrow and at the low end of the scale for both non-accredited and externally accredited groups. In this respect, both the median and mode of item 3, item 4, item 5, item 7, item 8, item 9, item 12, and item 15 were at the first level for both groups. See Table 3 for the means and standard deviations of the scores estimated for three continuous variables: *STEM_community*, *STEM_integration*, and *STEM_assessment*.

Although the externally accredited program course syllabi earned higher scores on average across all three variables, the highest average score could barely exceed level 2 and only in the *STEM_integration* category (see Table 3). Bivariate correlations (Pearson product-moment correlation coefficient r) between the variables were statistically

Table 2.
Descriptive Statistics for Ordinal Data

Ordinal Variables	Accreditation							
	Non-accredited			Externally accredited				
	Median	Mode	Max	Min	Median	Mode	Max	Min
1. Accessibility	1	1	4	1	3	3	3	1
2. Policies & expectations	1	1	4	1	2	1	4	1
3. Connectedness I	1	1	3	1	1	1	2	1
4. Connectedness II	1	1	2	1	1	1	2	1
5. Connectedness III	1	1	2	1	1	1	2	1
6. In-depth content knowledge	3	3	4	1	3	3	4	2
7. Beliefs, attitudes, values	1	1	4	1	1	1	4	1
8. Skills	1	1	3	1	1	1	4	1
9. Life-long learning	1	1	3	1	1	1	4	1
10. Integrated knowledge	1	1	4	1	2	1	4	1
11. Focus of grading	2	2	3	1	3	3	4	1
12. Formative assessment	1	1	3	1	1	1	2	1
13. Summative assessment	1	1	4	1	3	3	4	1
14. Authentic assessment	1	1	2	1	3	3	4	1
15. Self-regulation	1	1	1	1	1	1	2	1

Note. Continuous variables were created by taking the average of the scores in each ordinal variable. Item 2 and item 12 were not included in this process due to their low item-total correlations.

significant ($p < 0.05$). The correlations could be interpreted as moderate (see Table 4).

Table 3.
Descriptive Statistics for Continuous Data

Continuous Variables	Accreditation			
	Non-accredited programs		Externally accredited programs	
	M	SD	M	SD
STEM_community	1.42	0.34	1.57	0.33
STEM_integration	1.54	0.40	2.11	0.78
STEM_assessment	1.38	0.30	1.99	0.41

Note. Means (M) and Standard Deviations (SD) are only for courses with a syllabus.

Table 4.
Bivariate Relationships between Continuous Variables

Continuous Variables	STEM_community	STEM_integration	STEM_assessment
STEM_community	1	0.38**	0.31*
STEM_integration		1	0.47**
STEM_assessment			1

Note. * $p < 0.05$, ** $p < 0.01$.

Based on the results of the independent t -test, the differences between non-accredited and externally accredited programs were statistically significant for the variables of *STEM_integration* and *STEM_*

assessment: $t(55) = -3.69$, $p < 0.01$, Cohen's $d = 1.01$ for *STEM_integration* and $t(55) = -6.50$, $p < 0.01$, Cohen's $d = 1.79$ for *STEM_assessment*, showing a large practical significance in favor of course syllabi of externally accredited programs. A post-hoc power analysis estimated that the achieved power as 37% for scores in *STEM_community*, indicating that a larger sample size would be needed for statistical significance. Figure 1 presents a visual representation of the confidence intervals associated with the point estimates of means for each variable.

Discussion

The current study contributes to the international quality assurance efforts in course design, delivery, and evaluation at the higher education level by developing a comprehensive syllabus assessment scheme, specific to STEM subjects. Overall, the instrument yielded data indicating that it is useful for investigating STEM teaching practices with similar samples (cf. Cullen & Harris, 2009). Evidently, the instrument needs further development to eliminate inconsistencies in the STEM community measure. The research encourages scholars to conduct further studies to examine how the instrument performs in other contexts and for external, internal, or self-assessment purposes (Imbert & Kochar, 2002).

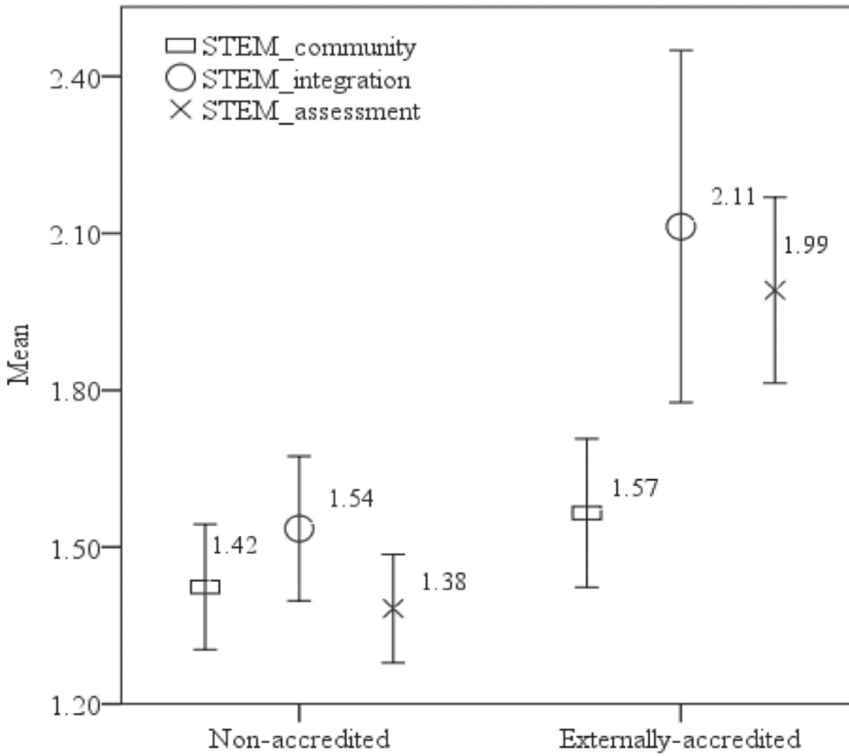


Figure 1. Confidence Intervals (95%) for Estimated Means

It is evident from this study that external accreditation has a practically important positive impact on ensuring that course designs are aligned with the STEM education praxis. The noteworthy differences between syllabi in non-accredited and externally accredited groups can be best explained by individual efforts of instructors teaching in the externally accredited programs (cf. Felder & Brent, 2003; Whetten, 2007). However, a dependence on extrinsic motivational causes alone (i.e., ABET accreditation) may challenge the transition process from an instruction-based teaching into a learner-centered one (Prados, Peterson, & Lattuca, 2005), particularly when the external motivation contradicts the intrinsic motivation of the instructors (Ryan & Deci, 2000). External accreditation may have extrinsically motivated the instructors in preparing their syllabi.

The below-par average performances in establishing a STEM community, linking the main subject area to other STEM disciplines, or incorporating STEM evaluation tasks may indicate a lack of support at the organizational level or a conflict between the

mission of the university and the practices at the classroom level (Eberly, Newton, & Wiggins, 2001). Given that 39% of the courses in the non-accredited programs and 21% of the courses in externally accredited courses had no syllabi, this may imply that the instructors in the STEM programs associated with the sample in this study need a clearly formulated policy on course syllabi and an extensive professional development that focuses on the benefits of establishing earlier contact with students (Habaneck, 2005).

Conclusion

ABET accreditation can be good preparation for EHEA universities to meet the Bologna Process standards. Similarly, the ABET accreditation process may guide EHEA universities to establish an effective internal accreditation mechanism or can provide the instructors with a motivation to self-assess their STEM teaching practices. Yet, I believe that no external accreditation will be as effective as an internal evaluation of performance at

the organizational level, supported by professional development opportunities to increase the effectiveness of teaching. Similarly, no internal quality assurance scheme will have a sustainable positive impact on quality assurance in course design, delivery, and evaluation if not supported by instructors' self-assessment of their practices.

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Appendix 1.
A Rubric to Assess STEM Teaching Praxes through Course Syllabi

Descriptors	STEM Community			
	1	2	3	4
1. Accessibility for out-of-class learning experience	No office hours allocated; no means of access (phone or email) is provided.	The instructor is available for prescribed number of office hours; no other means of access (phone or email) are provided.	The instructor is available for more than prescribed number of office hours; offers phone(s) or email.	The instructor is available for multiple office hours; multiple means of access including phone(s), and email; holds open hours in locations other than office (e.g., library or Moodle).
2. Policies & Expectations for Learning Centeredness	No policy or expectations are expressed.	Policies or expectations are limited to penalties or rewards.	Policies or expectations include penalties and rewards; types of assignments or weight of assignments or due dates are given.	Expectations are detailed with penalties, rewards, weights, and due dates; encourages students to participate in further development of the policies.
3. Connectedness I (Instructor to students)	No information about the academic or personal interests of the instructor is available.	Some information about the education or research interests of the instructor is available.	Some information about instructor's education, in addition to research interests or previously taught courses, is available.	Detailed information about instructor's education, previous teaching, research, and outside interests is available; a personal or a class web URL is given.
4. Connectedness II (Students to instructor)	No information is requested from the students.	Students are asked to contact the instructor for prerequisites of the course.	A student form is provided to learn about students' previous coursework and expectations from the course.	A student form is provided to learn about students' previous coursework, background experiences, and expectations from the course.
5. Connectedness III (Among students)	No study guide is available to students; collaboration prohibited or discouraged.	A limited study guide is available to students; the guide does not openly refer to collaboration among students.	A study guide is available to students and use of groups for work, and study is encouraged.	Collaboration (use of groups for class work or team projects) is required; students are encouraged to learn from one another or construct knowledge together.

STEM Integration				
Descriptors	1	2	3	4
6. The framework for in-depth content knowledge	No list of topics is given.	There is a list of topics but no cognitive objectives are given.	A list of topics with cognitive objectives is given; some external references or a textbook is available.	A list of topics with cognitive objectives is given; several external references and a textbook are available. Students are encouraged to achieve their own synthesis.
7. Beliefs/ Attitudes/ Values	No rationale or a need to learn is given.	A rationale or a need to learn is stated.	There is a rationale statement or project /assignment /homework allows students to discover their own connections.	Rationale and projects /assignments /homework allow students to discover their own STEM connections.
8. Skills	No list of skills is given.	Skills are listed as objectives, rationale, or prerequisites.	Objectives, the rationale, and the prerequisites include skills.	Objectives, the rationale, and prerequisites include skills in some other STEM area(s) in addition to the main subject.
9. Connection to life-long learning	No reference to out-of class learning.	Rationale includes a reference to employability or personal development.	Rationale includes a reference to employability and personal development that continue after class.	Rationale includes a reference to employability and personal development that continue after class; emphasizes metacognition skills.
10. Integrated & Interdisciplinary construction of knowledge	No links to other STEM areas.	Links to content or skills in at least one other STEM discipline.	Links to content and skills or beliefs in at least one other STEM discipline.	Links to content, skills, and beliefs in at least one other STEM discipline.

STEM Assessment				
Descriptors	1	2	3	4
11. Focus on Grading	No information about how grades would be assigned.	Grades are used to penalize or for losing points; focus is on failing.	Grades are earned; focus is on passing.	Grades are tied to learning outcomes; option for achieving points; focus is on learning.
12. Formative Assessment	No form of formative assessment.	There is some formative assessment that provides feedback.	A variety of formative assessment tasks are available; some rewriting or redoing of assignments allowed, but penalized.	Formative assessment provides students with regular feedback, rewriting and redoing of assignments (make-up) encouraged; formative assessment tasks are aligned with the expected learning outcomes (rubrics/clear criteria are used).
13. Summative Assessment	Summative assessment consists of mid-term or final exam grades alone.	There is some other summative assessment (quizzes, surprise pop-quizzes, etc.), yet midterms/ finals make the bulk of the final grade.	A variety of summative assessment tasks are available throughout the semester; students are prepared in advance for small summative tasks and the final (e.g., problem solving sessions), no surprise element. Midterms/finals make up the bulk of the final grade.	A variety of summative assessment tasks are available throughout the semester. Students are prepared in advance for small summative tasks and the final (e.g., problem solving sessions), no surprise element. Test scores or grades have minimal impact on the summative assessment of the students and are aligned with the expected learning outcomes (rubrics/clear criteria are used).
14. Authentic Assessment	No authentic assessment tasks are included.	Some written work is required.	Assessment tasks are closely related to life-long learning skills, such as portfolios, written and oral presentations, or projects.	Assessment tasks are closely related to life-long learning skills and incorporate just-in-time assessment tools, such as clickers and other technology.
15. Self-regulation	No evidence of developing self-regulation.	Rubrics are used as explicit and clear criteria for evaluation.	Self- and peer-assessment tasks are included with clear rubrics.	Students are involved in the design of the self- and peer-assessment tasks and corresponding rubrics.

Note. Some items of this rubric are adapted from Cullen and Harris (2009) with the written permission of the corresponding author.

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