Assessment of interdisciplinary competencies

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“If you only have a hammer,
you tend to see every
problem as a nail.”

— Abraham Maslow

Summary

The ability to work in multidisciplinary teams is currently seen as an important competency in university education for a variety of reasons: 1) Academicians and (under)graduate students alike are increasingly involved in trying to solve complex problems our society faces for which cooperation between different disciplines is required; 2) the areas where two or more disciplines meet are recognized as fields for innovative and fruitful research activities; 3) working towards interdisciplinary solutions for complex problems stimulates the development of a number of so-called '21st century skills', such as: cooperation & collaborative learning, thinking in a creative & innovative way and critical thinking.
However, within disciplinary curricula students are often not optimally prepared for the complexities of the multi-/ interdisciplinary work field.

Currently, a variety of initiatives within Utrecht University can be identified to close this educational gap, such as the development of interdisciplinary minors, courses and assignments as well as the development of a learning progression 'interdisciplinarity' which can be implemented within a disciplinary curriculum. These activities are indeed crucial to meet the needs of future employers who increasingly indicate the necessity of students being able 'to work and think in an interdisciplinary way'. However, one of the main challenges for interdisciplinary education is the assessment of interdisciplinary competencies. In this respect, educational specialists indicate that the lack of solid (rigorous, thorough) assessment criteria of interdisciplinary (writing)-products may hamper a legitimate way to qualify the achievements of students in interdisciplinary assignments or courses during their university education.

In this report, focused on the complexity of assessing interdisciplinary competencies, we will first elaborate on the concept of interdisciplinarity, then on the various competencies required to work in an interdisciplinary setting and finally on how to qualify interdisciplinary products and skills. For the assessment of interdisciplinary competencies, some rubrics ill be discussed and a matrix has been developed with a set of rubrics which can be used and adapted at will by teachers. These rubrics can be used to assess specific skills which are trained in an assignment, a course, a minor or throughout a learning progression 'interdisciplinarity' within the context of a disciplinary curriculum.
With this report, we hope to provide useful information to support teachers and students in training and assessing 'interdisciplinary working & thinking' as additional academic competency within a disciplinary environment.

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Introduction

Many of today's increasingly complex and global challenges, such as climate change, hunger and poverty, lifestyle diseases, overpopulation, loss of biodiversity and wildlife conservation require the joint involvement of researchers from different disciplinary backgrounds (from the natural and social sciences, humanities, but also intrinsically interdisciplinary fields such as environmental sciences and medicine) (*e.g.* Boix Mansilla *et al*., 2009; Holm and Winiwarter, 2017; IPBES, 2019; Orr *et al.* 2020; Shah 2020). As these problems also become increasingly pressing, specific skills that are key to solving them are becoming a crucial asset. Employers are therefore looking for individuals who can integrate knowledge and methods and are able to collaborate with experts from different fields, cultures and disciplines (Levy & Murnane, 2005; National Academies, 2005; NRC, 2009; AAAS, 2011). Overall, the demand for academicians who are well-educated to function in multidisciplinary teams and to achieve interdisciplinary solutions is high. To meet this demand and to ensure future welfare, we argue that higher education should focus on preparing students to deal with these complex real-world problems. This entails adding an interdisciplinary competency to the largely disciplinary curricula at universities to equip students with the interdisciplinary skills that they – and the world - are going to need.

Besides the fact that modern problem-solving largely demands input from and collaboration between multiple disciplines, the increasing urgency for interdisciplinary knowledge and skills has additional drivers. For one, efforts in education focused on interdisciplinary topics were reported to have a number of advantages besides the development of specific interdisciplinary competencies such as stimulation of deductive reasoning and critical thinking (Box1). Furthermore, scientific papers within disciplines often refer to literature from other disciplines, which is the case in even more than one third of all references in the scientific literature (Ledford, 2015). Such prevalence of cross-disciplinary referencing makes it necessary for the reader to muster a basic level of interdisciplinary thinking in order to grasp the meaning of these papers. In acknowledgement of this demand, the report "Vision & Change in Undergraduate Biology Education; a call to action" emphasizes the need for interdisciplinary education by devoting 'interdisciplinary thinking' as one of the six core competencies that every Biology student should master during their Undergraduate degree, formulated as the ability to "tap into the interdisciplinary nature of science" (AAAS, 2011). Another one of the six core competencies, communication, also addresses interdisciplinarity by emphasizing the need to teach students to communicate and collaborate with students from other disciplines. With these recommendations, the authors encourage a more prominent place of interdisciplinary training withing a disciplinary curriculum. Regrettably, pedagogical approaches which challenge students to actively integrate knowledge from multiple disciplines and gain advancement through such integration are still relatively limited or to date not well-developed (Repko, 2008; Repko & Szostak, 2016; Tripp & Shortlidge, 2019; Davidesco & Tanner, 2020).

This lack in development is caused by multiple issues concerning interdisciplinary teaching and learning. Some of these are rooted in the fundamental problem that there is no consensus on what interdisciplinarity encompasses (*e.g.* Olcese *et al*., 2014; Tripp & Shortlidge, 2019). This lack of a common definition results in a lack of common practices where different forms of interdisciplinarity are taught across and even within programs. A unified definition could help coordinate and strengthen educational efforts by facilitating an agreement on interdisciplinary competencies that a student should master in an assignment, course or curriculum (Tripp & Shortlidge, 2019). This in turn would make it easier to formulate more precise learning goals, interdisciplinary tasks and assessment strategies. Currently, the assessment of interdisciplinary competencies is still recognized as challenging. Mentkowski & Sharkey (2011) for instance argue that the assessment of integrative learning cannot be measured by using one single tool, as it encompasses a combination of knowledge, attitudes and

skills. Taken together, this results in sub-optimal educational settings that sometimes leave both teachers and students wondering what exactly is expected of them.

Following the above argument for a clarified concept of "interdisciplinarity", this report will start by looking into definitions of this term. The goal of this first part (A) is not to come up with an overarching definition but rather to assess what features are commonly mentioned in different definitions. Using these commonalities as a framework will help to better establish what interdisciplinary competencies students should master, which will be the aim of the second part (B). After discussing interdisciplinary core competencies, we will investigate in the third part (C) how these competencies can be assessed. To this purpose, we will also address the difficulties that typically arise in assessing interdisciplinary competencies and the products of interdisciplinary assignments. In each part, multiple papers concerning the topic will be summarized, emphasizing the most important viewpoints and/or findings of the authors. Finally, after a Discussion & Conclusion, the gathered information will be used to draft multiple learning goals and objectives specific for developing interdisciplinary competencies. In addition, an assessment matrix for interdisciplinary skills and -products is presented, which has been developed within the framework of this project. As it consists of a number of rubrics, teachers can tailor this matrix to the purposes of any course, minor or curriculum at hand, by adapting it to assess the interdisciplinary competencies that are being trained in the relevant assignment(s). In more specific terms, it can be used by teachers and faculties that seek to incorporate interdisciplinary teaching in their courses, helping them to effectively do so.

In summary, the goal of this report is to better understand what interdisciplinarity encompasses and how it can be adequately trained in disciplinary and interdisciplinary undergraduate programs. This should result in disciplinary students enriched with the ability of interdisciplinary thinking and hence better able to tackle the big and complex questions of a globalized world.

Overview of the papers, analyzed in this report

In Table 1, an overview is given of the papers summarized and discussed in the three parts (A-C) of this report.

TABLE 1
Overview of all the articles discussed in this report. For each article, the title, authors and year of publication is given, as well as the page number of this report where the discussion can be found.

TITLE PAPER	AUTHOR(S)	YEAR	PAGE
A. Understanding interdisciplinarity			
How we know it when we see it: conceptualizing and assessing integrative and applied learning-in-use	Mentkowski & Sharkey	2011	11
Modelling the demands of interdisciplinarity: toward a framework for evaluating interdisciplinary endeavours	Stein	2007	12
A framework to guide undergraduate education in interdisciplinary science	Tripp & Shortlidge	2019	15
B. Interdisciplinary competencies			
Vision and Change in Undergraduate Biology	AAAS	2011	19
Development and test of a model of interdisciplinary competencies	Claus & Wiese	2019	20
Developing a measure of interdisciplinary competence for engineers	Lattuca *et al.*	2012	23
Pedagogy for interdisciplinary habits of mind	Newell & Luckie	2019	26
A framework to guide undergraduate education in interdisciplinary science	Tripp & Shortlidge	2019	28
C. Assessment of interdisciplinary assignments			
Targeted assessment of student's interdisciplinary work: an empirically grounded framework proposed	Boix Mansilla & Duraising	2007	31
Targeted assessment rubric: An empirically grounded rubric for interdisciplinary writing	Boix Mansilla *et al.*	2009	33
Using concept maps to assess interdisciplinary integration of green engineering knowledge	Borrego *et al.*	2009	36
Assessing development of an interdisciplinary perspective in an undergraduate neuroscience course	Crisp & Muir	2012	38
Interdisciplinary assessment in the 21st century	Drake & Ruid	2017	39
A framework for analyzing interdisciplinary tasks: implications for student learning and curricular design	Svobodea *et al.*	2013	40
Meeting the challenge of interdisciplinary assessment	Olcese *et al.*	2014	43
Assessing interdisciplinary learning outcomes	Repko	2008	45
Interdisciplinary program assessment	Stowe & Eder	2002	47
Crossing boundaries: measuring undergraduates' interdisciplinary science understanding	Tripp *et al.*	2020	52
From Theory to Practice: Gathering evidence for the validity of data collected with the IDSR	Tripp & Shortlidge	2020	55
Interdisciplinary writing assignment profiles	Wolfe & Haynes	2003	57
Assessing students' disciplinary and interdisciplinary understanding of global carbon cycling	You *et al.*	2018	61

BOX 1
Advantages of multi- and interdisciplinary teaching

A variety of advantages for students have been mentioned when involved in multi- and interdisciplinary education:

1. Development of a complex understanding of different subjects (Lattuca *et al.*, 2004),
2. Stimulation of deductive reasoning (Nowacek, 2005),
3. Stimulation of a critical mode of thinking and attitude (Wolfe & Haynes, 2003),
4. Development of meta-cognitive reflection skills and problem-solving ability (Wolfe & Haynes, 2003; Boix Mansilla & Duraisingh, 2007; Leonard & Jean, 2007),
5. Development of the ability to take different viewpoints/analyse a problem from different perspectives (Liu *et al.*, 2008),
6. Increasing motivation and interest in different disciplines (Barab & Landa, 1997).

There are also advantages which are solely supported by interdisciplinary teaching and learning:

7. Stimulation of the integration of knowledge (Nowacek, 2005),
8. Supporting a higher order mode of thinking, resulting in students who more easily discover connections between subjects (Newell, 1998).

A Understanding interdisciplinarity

Introduction to this section

Before we can understand how to assess interdisciplinary competencies we first need to know what interdisciplinarity encompasses. The word has been widely used in the literature although a consensus on a definition has not yet been reached. The aim of this section is to give a short overview on the elements and concept of interdisciplinarity and point out the commonalities of different definitions. If we better understand the variety of definitions used we may better understand the difficulties that have arisen in identifying the required competencies and in assessing interdisciplinary tasks (which we will investigate in the next sections).

How we know it when we see it: conceptualizing and assessing integrative and applied learning-in-use

Mentkowski & Sharkey (2011). New Directions for Institutional Research, 149: 93-107.

In their article Mentkowski & Sharkey analyzed the development of interdisciplinary research and teaching. They focused on integrative and applied learning and what still needs to be done to better integrate interdisciplinary education in the disciplinary curriculum. Their goal was to identify multiple factors that influence the education and assessment of integrative learning.

Defining integrative learning

After setting up a multi-campus team, they started with agreeing on a basic definition of integrative and applied learning; "Integrative learning and applied learning is an understanding and a disposition that a student builds across the curriculum and co-curriculum, from making simple connections among ideas and experiences (integrative learning) to synthesizing and transferring learning to new, complex situations within and beyond the campus (applied learning)" (Rhodes, 2010). The team further agreed with previous work that both integrative and applied learning are essential for students to develop expertise (Feltovich *et al.*, 2006) and, if a faculty wants to teach and assess integrative and applied learning, it is important to realise that knowing and doing are strongly connected. Both aspects of learning develop together in a cyclical fashion (Mentkowski & Doherty, 1984).

The team also noted that performance in an interdisciplinary field needs to develop and that this growth can be assessed by defining teachable abilities which Mentkowski & Sharkey (2011) defined as "multidimensional learning outcomes that ultimately involve students' integration of knowledge and understanding, behaviours and skills, attitudes and self-perceptions, motivations and dispositions and habits of mind and value." (based on Anastasi, 1980; Sternberg, 1998). If students master the right skills and learn to transfer information from one context to another, this will result in adaptive instead of routine experts, which is becoming more and more necessary to be able to navigate and shape the globalized and fast-changing world we live in. Thus, during their education students ideally expand their network of abilities and can start to use them to solve complex problems in different contexts, making it possible to asses these abilities in different contexts across the curriculum. The authors also found that good feedback is essential in helping students expand their abilities.

Self-reflection

Mentkowski & Sharkey (2011) also emphasize the importance of reflection and self-assessment in learning to integrate. The students who effectively engaged in self-reflection were taught a self-assessment process that requires them to "observe their performance, interpret and analyse it, provide their own feedback and seek that of others, and judge its effectiveness in relation to criteria that afford a picture of their developing abilities". This means that teachers should invite and guide students to engage in self-assessment, along with teaching them how and when to self-reflect and routinely including self-assessment opportunities in the curriculum. For this approach to bear fruits, teachers must not solely assess students' work but also the quality of their self-reflection. In the next section (B), we will focus in more detail on interdisciplinary competencies.

Modelling the demands of interdisciplinarity: toward a framework for evaluating interdisciplinary endeavours

Stein (2007). Integral Review, 4(1): 91–107.

Stein begins his paper with looking into the history, evolution and present-day interpretation of interdisciplinarity. Thereafter, he draws attention to the difficulty of combining multiple disciplines. In his evaluation of interdisciplinary work, two factors that influence its quality stand out:

1. The complexity of cognition and collaboration,
2. The epistemological structure of interdisciplinary validity claims.

Defining interdisciplinarity

While researching the history of interdisciplinarity, Stein identified five factors that shaped the demand of interdisciplinarity over time:

1. The development of science (increased specialisation of disciplines),
2. Students' needs,
3. The need for professional training to work in multi-/interdisciplinary teams,
4. Original needs of societies,
5. Problems of university operation or even administration.

He also found that, despite the lack of consensus on the definition of interdisciplinarity, there seems to be an agreement that interdisciplinary work is based on the integration of multiple (at least two) disciplines. This forces us to first specify what a discipline is. Stein adopts Gardner's (2000) definition of a discipline as "the concepts and methods for thinking about specific types of questions and phenomena; concepts and methods that have been cumulatively accepted by experts as providing standards for determining the validity of answers". But this definition is just one view of many that have been held throughout the history of science. How we viewed disciplines over time has influenced the development of interdisciplinarity. Stein notes that interdisciplinarity today is roughly divided in three interdisciplinarity activities:

1. Interdisciplinary (or multidisciplinary) education; exposing students of all ages to various disciplines,
2. Problem-focused interdisciplinarity; combining multiple disciplines in some way to solve specific problems,
3. Synoptic interdisciplinarity; summarizing or using multiple disciplines to give an account of a general phenomenon.

Importance of expert collaboration

Campbell (1969) emphasized that it is very hard to become an expert in one discipline, which entails mastering the specific methods and techniques, as well as acquiring disciplinary knowledge. According to him it is impossible to become an expert in multiple disciplines and if tried this will result in shallowness. Stein adopts this view and underlines that in addition to become an expert in one discipline people should also use the competencies of others and collaborate to generate interdisciplinary knowledge. This means becoming an expert in one discipline and working together in teams for true interdisciplinarity. However, this requires finely tuned team-work skills: Stein argues that if two disciplines collaborate to solve a problem, neither of them should be dominant nor privileged over the other.

Multi-, cross-, inter and transdisciplinary

Stein (2007) proposed a cross-sectional, hierarchal taxonomy in which every new level (disciplinary, multidisciplinary, crossdisciplinary, interdisciplinary, transdisciplinary) has its own particular set of skills and demands and builds on the skills learned at the previous level(s) (Table 2). Stein (2007) based his definition of each level and the skills required to master them on the complexity of the concepts and practices it entails. However, he acknowledges that these definitions are far from perfect. They should be used as a starting point to define in

which category an assignment belongs and help teachers design assignments that are developmentally appropriate. This should be done by first determining which skills students already have to help identify the level of assignments the students can handle, and accordingly design the task based on the appropriate learning goals and competencies.

TABLE 2

A cross-sectional, hierarchical taxonomy of forms of inquiry showing the competencies of an individual and a group. Every level is more complex than the previous one and builds on the learned skills and knowledge of the previous level(s).

FORM OF INQUIRY	COMPETENCIES OF INDIVIDUALS	COMPETENCIES OF GROUPS
Disciplinary	**Requisite level of cognitive development:** *Highly elaborate abstract mappings.* Individuals demonstrate understanding of a specific set of characteristics of conceptions and one methodological approach. They are able to generate unique questions and contribute new research and findings in this area.	Group is able to produce new knowledge (or confirm existing knowledge) in a specific discipline by employing that discipline's set of concepts and methodologies.
Multidisciplinary	**Requisite level of cognitive development**: *Abstract systems.* Individuals demonstrate disciplinary competence and understand that their endeavours must be related to the endeavours of others in surrounding disciplines. They therefore come to know and use some concepts used in these disciplines.	Group is able to demonstrate disciplinary competence and relate the results produced by surrounding disciplines to its own, and relate its own results to others (e.g., communication between disciplines).
Cross-disciplinary	**Requisite level of cognitive development:** *Highly elaborate abstract systems.* Individuals demonstrate disciplinary competence and know how concepts and methodologies from other disciplines relate to their own, having mastered some concepts therein. They are able to constructively communicate with individuals from other disciplines in a problem-focused manner.	Group is able to demonstrate disciplinary competence and to constructively collaborate with groups from other disciplines in a problem-focused manner.
Interdisciplinary	**Requisite level of cognitive development:** *Multiple principles.* Individuals demonstrate competences in at least two disciplines. One is primary, yet they are able to employ the concepts and methodologies of another discipline well enough to employ the questions and findings therein. New understandings of the primary discipline result.	Group subsumes at least two disciplinary subgroups, with one as primary focus of expertise. Capable of solving problems that cannot be addressed by either discipline alone, typically in a problem-focused manner.
Transdisciplinary	**Requisite level of cognitive development:** *Beyond single principles.* Individuals demonstrate at least two disciplinary competences, neither of which is primary. They work and contribute to both and generate unique findings, conceptions, and artefacts as a result of an emergent transdisciplinary perspective. They are able to communicate with individuals from a variety of disciplines in a synoptic manner.	Group subsumes at least two disciplinary subgroups, neither of which is primary. Produces both problem-focused and synoptic knowledge, which cannot be reduced to either of the subgroup competencies. Capable of spawning new disciplines, and reforming existing ones in light of newly emergent perspectives.

Furthermore, Stein (2007) emphasises that students can only begin to understand and work on different levels, branch out and compare and integrate their own expertise with others after becoming disciplinary grounded (figure 1). Thus, general education should focus on the development of disciplinary expertise and only after acquiring this expertise should students' knowledge slowly be supplemented with knowledge from other disciplines. Over time, students should become transdisciplinarians as a result of the different emergent perspectives becoming available to them. In his model, Stein purposefully singles out meta-disciplinary reflection (Figure 1), arguing that it continuously exists alongside the growth of knowledge and broadens the view of even the most focused disciplinary expert simply by showing them that other disciplines exist and generate valuable knowledge.

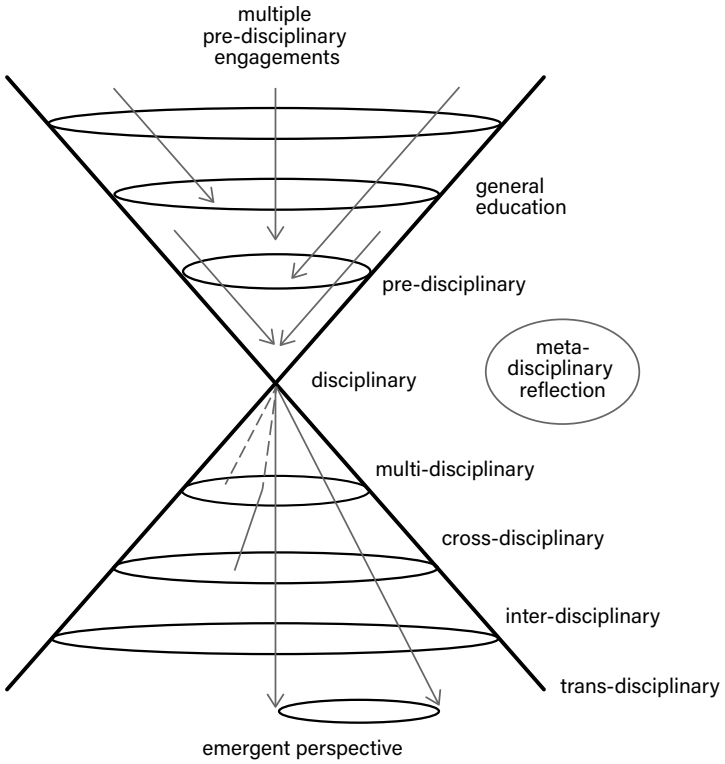


FIGURE 1

Funnel of expertise in which students first acquire disciplinary knowledge and afterward slowly start to branch out to a more multi-, cross-, inter- and finally transdisciplinary perspective.
Meta-disciplinary reflection is singled out because it influences each level.

A framework to guide undergraduate education in interdisciplinary science

Tripp & Shortlidge (2019). CBE—Life Sciences Education, 18(2): es3.

In their paper, Tripp & Shortlidge developed an interdisciplinary framework which will be considered in part B of this report. Before drafting this framework however, the authors sought to define "interdisciplinarity" first.

Defining interdisciplinary science

Interdisciplinarity is often viewed as the integration of perspectives from two or more disciplines in order to solve a complex problem, which forced Tripp & Shortlidge to first define what a discipline is. They agreed with Newell and Green's (1982) definition of a discipline as "a particular branch of learning or body of knowledge that can be distinguished by several factors, including the questions it asks via its ontological lens, epistemology and methodology regarding how these ideas are used to contribute to a body of knowledge composed of concepts, theories and facts". Based on the literature research they performed to identify the essence of interdisciplinarity, they showed that collaboration is essential. In addition, they emphasized that 'interdisciplinarity' is a process rather than an outcome. Tripp & Shortlidge (2019) proposed the following definition of interdisciplinary science: "interdisciplinary science is the collaborative process of integrating knowledge/expertise from trained individuals of two or more disciplines – leveraging various perspectives, approaches and research methods/methodologies – to provide advancement beyond the scope of one discipline's ability".

In a survey among faculty in the United States, Tripp & Shortlidge (2019) asked the question: "How do you define interdisciplinary science". Content-analysis of 184 open-ended survey responses resulted in six salient themes (Table 3).

TABLE 3
Top six themes / elements on how to define interdisciplinary science.

1. Involves two or more disciplines
2. Use of multiple/ differing research methods/methodologies
3. Collaboration among individuals
4. Need for other/ additional disciplinary knowledge/expertise
5. Having various perspectives, theories, approaches
6. Addresses problems that cannot be solved by one discipline

BOX 2
Definitions

To date there isn't one definition of interdisciplinarity that has been widely accepted. The varieties in definition seem to relate to differences in context in which the term interdisciplinarity is being used (research, education, social sciences or sciences, etc). Furthermore, the different definitions for interdisciplinarity, trans-disciplinarity, cross-disciplinarity or multi-disciplinarity are often used as interchangeable with one and another. It is important that individuals working in the interdisciplinary field are aware of the different definitions and actively prevent confusion.

Boix Mansilla's (2005) definition of interdisciplinary understanding is one that is widely used: "the capacity to integrate knowledge and modes of thinking in two or more disciplines to produce a cognitive advancement – *e.g.*, explaining a phenomenon, solving a problem, creating a product, **raising new questions** – in ways that **would have been unlikely** through single disciplinary means". Boix Mansilla in collaboration with other researchers (2009) drafted another, slightly different (see bold print) definition of interdisciplinarity, now also widely used: "the skill to integrate knowledge and modes of thinking from two or more disciplines which results in a cognitive advancement, such as the explanation of a phenomenon, solving a problem or producing a product, which **would not have been possible** if solely the knowledge of one discipline had been used".

As these definitions are quite similar, some parts are indicated in bold to emphasize how the definition changed over time.

Tripp and Shortlidge (2019) used these definitions and combined them into a definition of interdisciplinary science, which they formulated as: "the collaborative process of integrating knowledge/expertise from trained individuals of two or more disciplines – leveraging various perspectives, approaches and research methods/methodologies – to provide advancement beyond the scope of one discipline's ability". The US National Academies also drafted a definition of interdisciplinary research (IDR). They say it is "a mode of research by teams of individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research" (National Academies, 2005). This definition emphasizes two goals of integration and thus interdisciplinarity: 1) advancement in fundamental knowledge and understanding and 2) solving problems.

All definitions mentioned above emphasise the core of interdisciplinarity, namely the integration of disciplinary perspectives. Thus, to understand what interdisciplinarity truly encompasses one should first establish what a discipline is. Newell & Green (1982) defined a **discipline** as: "a particular branch of learning or body of knowledge that can be distinguished by several factors, including the questions it asks via its ontological lens, epistemology and methodology regarding how these ideas are used to contribute to a body of knowledge composed of concepts, theories and facts". Gardner (2000) set up a similar definition: "the concepts and methods for thinking about specific types of questions and phenomena; concepts and methods that have been cumulatively accepted by disciplinary experts as providing standards for determining the validity of answers".

Transdisciplinarity is most often interpreted as the incorporation of non-academic knowledge or perspectives within university education and research. Thus, it dissolves the boundaries between society and the conventional disciplines and organizes teaching and learning around the construction of meaning in the context of real-world problems or themes (Klein, 2004).

In a more abstract way, it has been defined as "a comprehensive framework that tries to go beyond combining existing disciplinary approaches in an interdisciplinary fashion to create new frameworks, new overarching syntheses" (Cantar & Brumar, 2011).

A different, but related, field is "Boundary crossing", which refers to the act of crossing boundaries between one's own and others' practices and perspectives with the aim of making new connections, learning from 'the other' and co-creating new practices (Akkerman & Bakker 2011; Oonk & Gulikers, 2018).

Crossdisciplinarity is a general overarching concept defined as "a general term used to refer to any activity that involves two or more disciplines" (Szostak, 2015).

If two or more disciplines are discussed but not integrated, one speaks of multidisciplinarity which is defined as "when scholars explore a topic from different disciplinary perspectives but fail to integrate or combine them". Since this is a rather negative formulation, one could also formulate it in a more positive way as "when scholars explore a topic from different disciplinary perspectives to get a fuller understanding of the complexity of the topic". Such a multidisciplinary view is often a required step towards solving complex problems.

B Interdisciplinary competencies

Introduction to this section

On the levels of assignments, courses, programs and institutions, the aim is to teach students a certain set of competencies. Competencies are the skills, knowledge and attitude necessary to be able to solve specific problems under certain circumstances (Friesen & Anderson, 2004; Sampson & Fytros, 2008; El Asame & Wakrim, 2018). All of an individual's competencies combined make up an individual's professional repertoire (Guthrie, 2009), which influences what kinds of problems a person can solve. A well-trained academic should have both disciplinary and interdisciplinary competencies in their professional repertoire. In this Part of the report we will focus on the literature in which the competencies are described required for interdisciplinary thinking and working.

Vision & Change in Undergraduate Biology Education: A call to Action

American Association for the Advancement of Science (2011). Final report, Washington, DC.
LINK: http://visionandchange.org/finalreport

Within Biology, a large number of initiatives to improve Biology education are based on this influential report published in 2011. Interdisciplinarity was emphasized as one of the six core competencies that every Biology student must develop during their undergraduate degree (AAAS, 2011). The first three competencies are action skills which require students to:

1. apply the process of science,
2. use quantitative reasoning,
3. use modelling and simulation.

The last three competencies are focused on students' ability to:

4. tap into the interdisciplinary nature of science,
5. communicate and collaborate with other disciplines,
6. understand the relationship between science and society.

The first three competencies are a prerequisite for developing competency four, five and six. If a student has mastered all competencies, this means that he/she will be able to conduct good interdisciplinary research (competency 4), which is also reflected in the ability to effectively work with other disciplines (competency 5) and is rooted in the ability to understand the link between societal and scientific problems (competency 6). This results in students who have the professional repertoire to address real-world problems. This capability is worth investing, and investment is needed: the six competencies must be learned over time and through various assignments and courses in order to achieve the aim that students are, at the end of their program, able to effectively work with students from different disciplines on complex problems our current society faces.

Combining the competencies pinpointed in the Vision & Change report with competencies mentioned in other papers, will give us an idea of what a student should learn and master to become a disciplinarian well capable to work in multidisciplinary teams achieving interdisciplinary solutions to complex problems. The present section will further focus on these competencies and learning objectives.

Development and test of a model of interdisciplinary competencies

Claus & Weise (2019). European Journal of Work and Organizational Psychology, 28(2), 191-205.

The authors conducted three studies in which they focused on interdisciplinary teamwork. This was their response to the observation that teamwork in interdisciplinary projects is often found challenging and where frustrations can easily arise (Epstein, 2005). This often causes projects to be divided into disciplinary sub-projects. Consequently, precious potential for innovative integration of disciplines is lost (Rogers *et al.*, 2005). Previous work has mainly focused on competencies of the team, but individual competencies are also an important factor in enabling an interdisciplinary team to function efficiently & productively (Bronstein, 2003; Epstein, 2005). Claus & Weise focused on understanding such impact of individual competencies on interdisciplinary teamwork. Their focus was mainly on the competencies related to skills.

Study one

The aim was to draft a model of interdisciplinary competencies by interviewing multiple experts on interdisciplinarity. They had to identify critical incidents during interdisciplinary collaboration that either showed someone working very well or very poorly with a team member from a different discipline. The incidents where then rated for their relevance, and critical behaviours were identified and classified as competencies. After analysing and clustering all the behaviours together, the authors included four interdisciplinary competencies (initiative for exchange, target group-specific communication, knowledge integration, reflection & appreciation) in their model (Table 4). In many incidents behaviours from multiple competencies were involved, which meant that the dimensions are not independent but rather a composite that creates good interdisciplinary working behaviour. Another interesting finding which appeared in the experimental data: Meta-reflection did not appear to play a significant role in the process, not even in the ability to quickly connect information from different disciplines. In previous research, however, the importance of meta-reflection has been emphasized (Bunderson, 2003).

↓ Table 4

TABLE 4
Initial model of interdisciplinary competencies based on four dimensions.
(-) refers to negative behavioural indicators.

DIMENSION	BEHAVIOURAL INDICATORS
Initiative for exchange	▪ Making suggestions ▪ Proposing solutions ▪ Initiating concrete discussions ▪ Abstract interactions (-) ▪ Giving up (-) ▪ Waiting for others to act (-)
Target group-specific communication	▪ Flexible adjustment to different audiences ▪ Bringing stakeholders on board ▪ Translating between disciplines ▪ Patience in explaining ▪ Communicating on different levels of abstraction (-) ▪ Forcing own opinion on others (-)
Knowledge integration	▪ Search for connections ▪ Intellectual curiosity ▪ Openness to others' arguments ▪ Active integration
Reflection and appreciation	▪ Realizing own limits ▪ Upholding one's own quality criteria ▪ Accepting others' premises ▪ Taking different approaches and methods seriously ▪ Lowering own standards (-) ▪ Ignoring methods of own discipline (-) ▪ Considering the other as incompetent (-) ▪ Taking credit for others' achievements (-)

Study two

The authors wanted to test their model developed in their first study. Furthermore, they wanted to develop a scale on which the experiences of employees in interdisciplinary collaborations could be measured, focusing on self-reported interdisciplinary competencies. As a validation, the authors tested what influence experience and the significance of interdisciplinarity for the job had on self-reported interdisciplinary competencies. They conducted an online survey among employees with experience in the interdisciplinary field. The validation showed that the fourth dimension, reflection and appreciation, should be split and that appreciation of other disciplines is an attitudinal prerequisite for interdisciplinary work that might make collaboration easier (Table 5). In addition, each year of experience in interdisciplinary work increases a person's ability to initiate exchange (competency 1) and reflect on his/her own disciplinary perspectives (competency 4).

↓ Table 5

TABLE 5
Survey conducted in study two amongst employees who work in the interdisciplinary field. For each indicated Dimension, representative statements from the survey are shown in the column named 'Item text.'

DIMENSION	ITEM TEXT
Initiative for exchange	▪ It is easy for me to make specific suggestions in order to create a basis for discussion in an interdisciplinary team, ▪ Often, I am the person who has the ideas for interdisciplinary projects, ▪ It is easy for me to take the initiative in an interdisciplinary meeting.
Target group-specific communication	▪ In interdisciplinary teams, it is difficult for me to avoid unnecessary technical terms, ▪ In interdisciplinary teams, I find it difficult to get my point across, ▪ It is not a problem for me to adapt my language so everyone in an interdisciplinary team understands, ▪ Regarding language, I find it hard to engage with team members from different disciplinary backgrounds.
Knowledge integration	▪ In interdisciplinary work, I am good at connecting and integrating knowledge from different disciplines, ▪ In interdisciplinary teams, I succeed in connecting different disciplines content-wise, ▪ In interdisciplinary teams, I can easily comprehend what other members work on with regards to content.
Reflection and appreciation	▪ I uphold the quality criteria of my own discipline in interdisciplinary teams, ▪ I can very precisely name the questions my discipline is in charge of and how my discipline differs from others, ▪ I can very precisely name the methodological and content-related features of my discipline.

Study three

The authors wanted to replicate the findings of their second study and to show that the model could be used on a more diverse sample. Furthermore, they wanted to study the relationship between interdisciplinary competencies and related concepts. The final goal was to validate that for interdisciplinary team outcomes, interdisciplinary competencies are a better indicator than disciplinary competencies. Again, an online survey was conducted amongst employees who work interdisciplinarily, with an aim to include more non-academic participants this time. The findings showed that the interdisciplinary competencies were mostly related to interest in interdisciplinary work, teamwork, self-efficacy and a general preference for teamwork. These constructs can be motivational and attitudinal prerequisites for successful interdisciplinary teamwork and can be used as indicators for the effort someone will invest in developing interdisciplinary competencies. It also shows that individuals will rate their interdisciplinary competencies higher if they depend more on others' input while doing their own work. This indicates that interdisciplinary competencies might develop as a necessity to cope with interdisciplinary requirements.

Lastly, the authors found that interdisciplinary competencies did predict team effectiveness and satisfaction better than general teamwork competencies and that 'knowledge integration' and 'target-group-specific communication' were the core competencies for interdisciplinarity. This led to the conclusion that successful interdisciplinary teamwork requires additional competencies as compared to disciplinary teamwork competencies.

Developing a measure of interdisciplinary competence for engineers

Lattuca et al. (2012) In: American Society for Engineering Education.

Lattuca *et al.* (2012) describe how they develop and test a survey to measure interdisciplinary competency of engineering students. Their goal was to develop a tool that could measure interdisciplinary competence in a large number of students across programs and institutions. They identified eight dimensions of interdisciplinary competence in recent literature and used these as a set of survey items. The survey was administered in 30 U.S. engineering schools.

Eight dimensions of interdisciplinary competence

The authors interpreted the dimensions of interdisciplinarity as a developmental learning trajectory for interdisciplinary competence. According to this trajectory, students must first be grounded in their own disciplines, then expand that knowledge to other disciplines before being able to integrate them. The authors' interpretation of the eight dimensions is summarised below.

1. *Awareness of disciplinarity*

Disciplines are seen as fundamental to the creation of knowledge and to interdisciplinarity. Being aware of how disciplines are structured should contribute to students' willingness to cross disciplinary boundaries and take other disciplinary views into account.

2. *Appreciation of disciplinary perspectives*

Being aware of disciplines is not equal to appreciating disciplinary perspectives. A student must first identify the strengths and weaknesses of disciplines, which will eventually result in appreciation and more specific knowledge of how a certain discipline can contribute to solving a problem.

3. *Appreciation of non-disciplinary perspectives*

Students should not solely consider academics but must also realise that, in real-life, non-academic stakeholders often play a part in the problem-solving process. Thus, students must be aware of the perspectives of non-academic communities to develop more encompassing interdisciplinary competence.

4. *Recognition of disciplinary limitations*

Being open to a variety of disciplinary and non-disciplinary sources may result in more critical awareness of the limitations of a discipline. Being conscious of such restrictions is important for making a grounded decision in either including or excluding a discipline or a disciplinary theory in the problem-solving process, based on its relevance and/or credibility.

5. *Interdisciplinary evaluation*

Concerning the evaluation of interdisciplinary work and programs, Lattuca *et al.* (2012) concluded that thus far, no good method has been developed. To successfully teach interdisciplinary thinking, the effectiveness of interdisciplinary work performed by students needs to be evaluated before teaching can be improved. The authors do not mention in what way such evaluation should occur, solely that interdisciplinary education should result in making students become more aware of and appreciate the knowledge, methods and perspectives of their own and other disciplines, as well as give them a critical understanding of their limitations.

6. *Ability to find common ground*

Finding common ground makes it possible to integrate knowledge from different disciplines. Hence, the ability to find common ground is considered to be fundamental to the notion of interdisciplinarity. To create common ground it is often required not only to evaluate disciplinary insights but also to modify, reinterpret or rectify

specific concepts, components or subsystems in order to emphasize commonalities so that linkages and relationships can be identified to facilitate integration.

7. *Reflexivity*

The interdisciplinary process is necessarily a reflexive one. Reflection allows to evaluate sources of information on complex problems or issues. Interdisciplinary competence also involves being able to reflect on one's own chosen approach, including one's biases and the choices made during the problem-solving process.

8. *Integrative skill*

Often seen as the hallmark of interdisciplinarity, a student must be able to integrate knowledge and perspectives of the chosen disciplines to solve a problem or produce cognitive advancement. Such integration should stretch beyond the boundaries of one discipline and should provide a comprehensive explanation greater than the sum of its disciplinary parts for the given phenomenon.

Three scales of interdisciplinary competence

Lattuca *et al.* conducted a survey at 30 U.S. engineering schools in which students had to self-assess their interdisciplinary abilities. After factor analysis of the data, nine separate scales for learning outcomes emerged, three of which were related to interdisciplinary competence (Table 6). The statistical analysis further provided some evidence supporting the validity of these three scales, but the authors emphasise that more research is needed to further test and improve them. It would be especially useful to identify direct measures of interdisciplinary knowledge and skills in future research. The three validated scales are described below.

1. *"Interdisciplinary skills" scale*

This scale assesses student's perception of their ability to think about and use different disciplinary perspectives in solving interdisciplinary problems, or to make connections across disciplinary boundaries.

2. *"Reflective behaviour" scale*

The questions pertaining to this scale address students' reflexivity and include items that assess students' perceived ability to recognize when they need to reconsider the direction of their thinking and problem-solving approach.

3. *"Recognizing disciplinary perspectives" scale*

This scale analyses students' perceived understanding of disciplinary knowledge, methods, expectations and boundaries and how disciplinary knowledge might be applied in different situations.

TABLE 6

The questions relating to the three different scales, to be answered by the students (strongly disagree, disagree, neutral, agree or strongly agree) to assess their own interdisciplinary skills (from Lattuca *et al.*, 2012).

FACTOR	ITEM STEM: To what extent do you agree or disagree with each of the statements below? (5-point scale)
Interdisciplinary Skills (Alpha = .790)	I value reading about topics outside of engineering.
	I enjoy thinking about how different fields approach the same problem in different ways.
	Not all engineering problems have purely technical solutions.
	In solving engineering problems I often seek information from experts in other academic fields.
	Given knowledge and ideas from different fields, I can figure out what is appropriate for solving a problem.
	I see connections between ideas in engineering and ideas in the humanities and social sciences.
	I can take ideas from outside engineering and synthesize them in ways that help me better understand.
	I can use what I have learned in one field in another setting.
Reflective Behavior (Alpha = .730)	I often step back and reflect on what I am thinking to determine whether I might be missing something.
	I frequently stop to think about where I might be going wrong or right with a problem solution.
Recognizing Disciplinary Perspectives (Alpha = .684)	If asked, I could identify the kinds of knowledge and ideas that are distinctive to different fields of study
	I recognize the kinds of evidence that different fields of study rely on.
	I'm good at figuring out what experts in different fields have missed in explaining a problem/ solution

Scale: 1 = Strongly disagree; 2 = Disagree; 3 = Neither agree or disagree; 4 = Agree; 5 = Strongly agree.

Pedagogy for interdisciplinary habits of mind

Newell & Luckie (2019). Journal of Interdisciplinary Studies in Education, 8(1): 6-20.

A list of pedagogies that promote interdisciplinary habits of mind was set up by Newell & Luckie. This list was shared at a conference on interdisciplinary pedagogy, where multiple participants got to propose additions, deletions and/or corrections. Afterwards, it was organized into categories representing different parts of the interdisciplinary process during which certain habits of mind are developed (based on each corresponding Repko step; i.e. drawing, modifying, integrating and evaluating insights from different disciplines) (Repko, 2012). The habits of mind found by the authors and participants are summarized below.

Interdisciplinary habits of mind

1. **Drawing insights from diverse perspectives into complex issues**
    1. Strive for adequacy in (the narrowly relevant concepts and theories of) each discipline, as well as a feel for its perspective,
    2. Seek out diversity of perspectives for richer and more comprehensive understanding,
    3. Identify perspectives and knowledge in relevant interdisciplinary fields,
    4. Identify pertinent knowledge and information in diverse disciplines and fields using digital technologies,
    5. In interdisciplinary collaborations, be alert to relevant approaches of other team members and their disciplines.

2. **Evaluating insights**
    1. Assume every disciplinary perspective has at least a kernel of truth,
    2. Assume whatever you're attempting has probably been tried before, at least in part,
    3. Proceed methodically even though the disciplines from which you draw employ different methods,
    4. Bracket and set aside/suspend personal convictions,
    5. Recognize all sides of an argument, avoiding overstatement and overconfidence,
    6. In evaluating disciplinary insights, look for strengths in arguments you dislike and weaknesses in those you like.

3. **Modifying insights**
    1. Seek commonalities not compromises, that is, win-win situations (in modifying and integrating insights),
    2. Think holistically, contextually, and systemically,
    3. Think dualistically, that is either/or (in drawing insights from disciplines) but also inclusively, that is both/and (in integrating their insights),
    4. Embrace contradiction – ask how it can be both,
    5. Use techniques for judging on conflicts between disciplinary insights in order to create common ground.

4. **Integrating insights into comprehensive understanding of issue**
    1. Look for unexamined linkages and unexpected effects,
    2. Seek unanticipated effects by re-contextualizing; look at different time frames, scales and cultures,
    3. Expect (an interplay of) multiple causes and effects,
    4. Resist the urge to assign numbers to things not inherently quantitative, especially if they can be viewed differently from different perspectives,
    5. Don't fall in love with a solution until you understand the full complexity of the problem,
    6. Strive for balance (between disciplinary perspectives),
    7. Integrate as you go (instead of waiting for all disciplinary insights),

8. Value intellectual flexibility and playfulness,
9. Seek understanding as a response to theoretical perspectives and empirical patterns of behaviour,
10. In constructing comprehensive understanding, be responsive to all perspectives but do not be dominated by one,
11. Persuade your audience with evidence, not claims; note that disciplines have different standards of evidence.

A framework to guide undergraduate education in interdisciplinary science

Tripp & Shortlidge (2019). CBE—Life Sciences Education, 18(2): es3.

As a response to the Vision & Change report (AAAS, 2011), Tripp and Shortlidge developed the Interdisciplinary Science Framework (IDSF). More specifically, they reacted to the statement that interdisciplinarity should become a key competency in undergraduate Biology majors because of the ever-increasing interdisciplinary nature of complex problems (Stokols *et al.*, 2008; AAAS, 2011; Klein, 2015; You *et al.*, 2018). The IDSF should aid instructors in establishing learning goals and outcomes related to interdisciplinary science and guide the development and assessment of interdisciplinary work in undergraduate science education.

Interdisciplinary science framework (IDSF)

The authors took note of the previously mentioned finding that in order to develop interdisciplinary understanding, students must have a basic understanding of the contributing disciplines (i.e. disciplinary grounding) and must understand how integrating perspectives from multiple disciplines may result in finding novel solutions (i.e. advancement through integration) (Boix Mansilla & Duraisingh, 2007; Öberg, 2009). Tripp & Shortlidge (2019) also emphasized the importance of disciplinary humility. These insights combined with multiple research methods and collaboration across disciplines were the groundwork for the IDSF (Figure 4), whose five core criteria are summarized below.

1. **Disciplinary humility**
    1. Developing humility and respect towards other disciplines,
    2. Being able to collaborate with experts from different disciplines,
    3. Reflecting and being aware of ones' own limitations and personal biases,

2. **Disciplinary grounding**
    1. Defined by Tripp & Shortlidge as the students' deep knowledge on one discipline and provisional knowledge on the other disciplines that will be integrated,
    2. Being able to draw connections between multiple disciplines.

3. **Different research methods**
    1. Being knowledgeable on different research methods used in different disciplines,
        a. Resulting in being better able to tackle real-world problems.
        b. Only being knowledgeable on the research methods (tools and/or instruments) necessary to solve the problem or research question.
    2. Curricula should discuss the ontological and epistemological components of a discipline, including the methodologies used (i.e. the philosophical assumptions and rationale for using the indicated research methods).

4. **Advancement through integration**
    1. Being able to use information flexibly, not reciting learned information.
    2. Being able to mix, connect and apply information which will result in new insights or ideas,

5. **Collaboration across disciplines**
    1. Helps increase students' disciplinary humility, gain better understanding of their disciplinary grounding, expand their awareness of the purpose of various research methods and achieve integration across disciplines,
    2. Being able to identify common ground,
    3. Having a good interdisciplinary grounding; being aware of perspectives, limitations and strengths of other disciplines.

4. Being able to identify commonalities and discrepancies between disciplines.
5. Having an open mind and a focus on gaining advancement through integration,

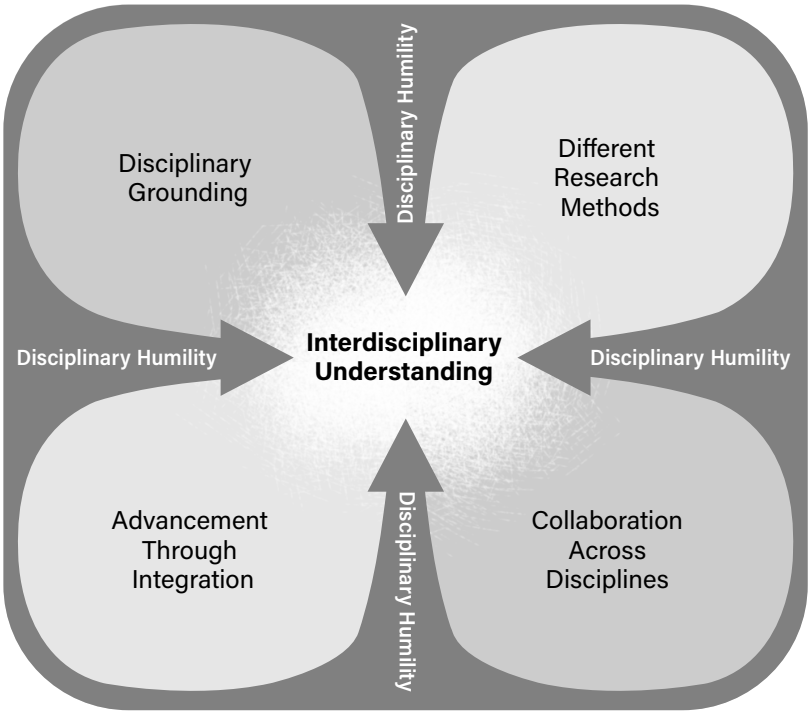


FIGURE 4

The interdisciplinary science framework (IDSF) with its five core criteria, used for guiding students to tap into the interdisciplinary nature of science.
If a student masters all these criteria, he/she will have a good interdisciplinary understanding.

C

Assessment of interdisciplinary assignments

Introduction to this section

In the previous section we focused on some papers describing relevant interdisciplinary competencies that students should have after completing an assignment, course or program. To establish whether a student has acquired these, we must be able to assess the progress students make with respect to these various interdisciplinary competencies. Assessments will not only show the progress students are making but will also give teachers a tool for quality control. Furthermore, it will give the faculty the possibility to check if the standards of the curriculum are met in interdisciplinary assignments.

In this part of our report a set of papers will be summarized in which a wide variety of assessment methods are described. Some papers also describe the difficulties concerning interdisciplinary assessment. A summary of these various difficulties will be presented and discussed.

Targeted assessment of student's interdisciplinary work: an empirically grounded framework proposed

Boix Mansilla & Duraising (2007). The Journal of Higher Education, 78(2): 215-237.

A framework is provided by Boix Mansilla & Duraising that serves as an assessment method applicable to a broad variety of assignments (writing, presenting, etc.). The authors interviewed multiple faculty members, teachers and students to identify concepts that are valuable in the assessment of interdisciplinary work. This resulted in the following three core dimensions (which will be elaborated on later):

1. Disciplinary grounding
2. Advancement through integration
3. Critical awareness

A good final product should clearly present the student's interdisciplinary understanding. Boix Mansilla & Duraising defined this as the capacity of a student to integrate the knowledge and perspectives of two or more disciplines resulting in cognitive advancement. It is prerequisite that this cognitive advancement could not have been achieved by solely using the knowledge and perspectives of one discipline. Furthermore, the product is deemed "good" if:

1. it is acceptable according to its epistemic function (*e.g.* explaining a phenomenon, concept, *etc.*),
2. it is credible by the degree to which it reflects previously established norms and understandings,
3. it is relevant when it expands productively beyond prior knowledge,
4. it is provisional in that it is subjected to critique and can always be altered in light of new evidence.

Boix Mansilla & Duraising further argued that the general description of their framework makes it applicable in all disciplines. Before it can be used, however, it should still be adjusted to the assignment specifics and the disciplinary requirements of a course or program. The authors also note that the framework can only be applied to a broad variety of assignments if the given tasks provide the student with the opportunity to show interdisciplinary understanding and insight. Finally, the framework should help to identify (and hence learn from) common pitfalls and misconceptions, such as attempting to integrate too many disciplines, focusing too much on one specific discipline, or using unexplained disciplinary jargon.

Three core dimensions of interdisciplinary work

As announced earlier, we now return in more detail to the three core dimensions to be assessed in interdisciplinary work, as formulated by Boix Mansilla & Duraising.

1. **Disciplinary grounding:**
    1. The student has a good level of knowledge, understanding and insight in a discipline,
    2. The student is familiar with the common theories and knowledge of a discipline,
    3. The student knows the common methods used in a discipline,
    4. The student can communicate within a discipline,
    5. The student has knowledge on the critiques within a discipline,
    6. The student finds the right balance between focus on disciplinary knowledge and meta-reflection (neither too little nor too much of either)
    7. The student can communicate disciplinary knowledge to a multidisciplinary audience.
    8. Assessment: it must be clear which disciplines and perspectives were selected and why. The selection and application of disciplinary knowledge and modes of thinking to solve an interdisciplinary problem must be appropriate.

2. **Advancement through integration:**
    1. The student expands his/her knowledge and understanding through the integration of disciplinary perspectives,
    2. The student can use multiple integration methods (*e.g.* conceptual frameworks, graphic presentations, models, metaphors and complex explanations and solutions),
    3. The integration results in a more complex, effective and empirically grounded product,
    4. The student does not solely integrate disciplinary information but also uses this integration to generate new conceptual models, explanations, insights and solutions (i.e. the student shows a level of innovation).
    5. Assessment: the focus shouldn't be on the quantity of information but on the integrative qualities of the product and the student's capacity to use existing information in a novel situation.
        a. The product clearly shows the added value of the integration of multiple disciplines (clear evidence of the enrichment by integration and/or loss of information and strength if no integration had taken place, or if a different set of disciplines had been integrated),
        b. Evidence of disciplinary integration (*e.g.* use of graphic presentation, models, metaphors, complex explanations and solutions to a problem),
        c. Evidence of cognitive advancement as a result of the integration of the disciplines,
        d. The final product is more than simply the sum of its disciplinary parts.

3. **Critical awareness:**
    1. The student can objectively reflect on the strengths and weaknesses of the chosen disciplinary perspectives,
    2. The student shows that the product has a clear goal,
    3. The background information as well as the problem invite an interdisciplinary view and approach,
    4. The student clearly defines the role of the different disciplines in solving the problem,
    5. The student clearly weighs and compares the different disciplinary perspectives,
    6. The student clearly discusses and reflects on the strengths and weaknesses of the chosen interdisciplinary approach,
    7. The integration process is actively criticised, revised and there is always room for alterations,
    8. The student uses a meta-disciplinary approach and has a critical view on the chosen interdisciplinary approach,
    9. The student is, during the whole process, aware of disciplinary differences, in knowledge and modes of thinking, resulting in advancement, compromises and limitations which are made clear in the integration.
    10. Assessment: there must be evidence of a critical stance, clear communication of the strengths and weaknesses of the chosen (interdisciplinary) approach and the limitations that are associated with an interdisciplinary mode of thinking.
        a. The final product clearly shows that a student has thought about the limitations of multiple disciplines, the opportunities to integrate knowledge and methodological differences,
        b. The final product addresses a clearly defined problem which invites an interdisciplinary approach.

Targeted assessment rubric: An empirically grounded rubric for interdisciplinary writing

Boix Mansilla et al. (2009). The Journal of Higher Education, 80(3): 334-353.

The targeted assessment rubric for interdisciplinary writing is an empirically tested assessment method for interdisciplinary writing assignments. This paper is an extension of Boix Mansilla & Duraisingh previous paper from 2007. The rubric (appendix A) assesses an interdisciplinary product based on ten assessment elements grouped in four categories. These categories are:

1. Purposefulness,
2. Disciplinary grounding,
3. Integration,
4. Critical awareness.

The students are rated on a scale of 1 to 4 based on the following four levels (which will be elaborated on later on) for each of the four categories:

1. Naïve interdisciplinary understanding,
2. Novice interdisciplinary understanding,
3. Apprentice interdisciplinary understanding,
4. Master interdisciplinary understanding.

The authors designed the rubric as a dynamic tool that can be used to assess a variety of assignments. The rubric should also aid in and further stimulate the development of the students' interdisciplinary understanding. Boix Mansilla *et al.* (2009) defined this interdisciplinary understanding as "the skill to integrate knowledge and modes of thinking from two or more disciplines which results in a cognitive advancement, such as the explanation of a phenomenon, solving a problem or producing a product, which would not have been possible if solely the knowledge of one discipline had been used" (based on the definition of Boix Mansilla *et al.*, 2000; Boix Mansilla & Duraising, 2007). The authors thus found that interdisciplinary understanding is rooted in a solid disciplinary understanding and that integration of disciplinary insights, perspectives and knowledge is essential and should result in the development of a new model, solution, insight or explanation.

In assessing students' interdisciplinary understanding, Boix Mansilla *et al.* (2009) found that students must exhibit expertise in, and broad knowledge on, the disciplines used. The assessor should identify parts of the work that show the integration of different disciplinary perspectives and that explain the cognitive advancements of this combination. To produce high-standard interdisciplinary work, the authors concluded that a student should thoroughly understand the goal of the assignment and actively criticize and judge their own work (weighing the different disciplinary possibilities, making adjustments to reach the goal, and recognizing the limitations of their interdisciplinary approach). The authors grouped their findings into four assessment categories, of which a more elaborate description can be found below.

Four assessment categories and ten assessment elements

1. Purposefulness

This category examines the degree to which a student exhibits clarity about the goals and target audience of their interdisciplinary writing assignment. Two questions should guide the assessment:

1. Does the main question invite an interdisciplinary approach?
    a. The scope of the problem is not too broad nor too small,

    b. A multidisciplinary approach is needed to find the solution.
2. Does the product effectively communicate the findings to the intended audience?
    a. There is no use of unexplained disciplinary jargon.

2. Disciplinary grounding

This category assesses the student's understanding and selection of the disciplines as well as the use of disciplinary knowledge. Two questions guide this assessment:

1. Does the student accurately and effectively use disciplinary knowledge (*e.g.* concepts, theories, perspectives, findings, examples)?
    a. The text is not just a summary of the isolated pieces of information from different disciplines,
    b. The text is easily readable, providing information that is supported by examples.
2. Are disciplinary methods used accurately and effectively (*e.g.* experimental design, philosophical argumentation, textual analysis)?
    a. Differences and similarities between methods are acknowledged and investigated.

3. Integration

This category assesses how perspectives are selected and if connections between disciplines are made and articulated clearly. Furthermore, the benefit of integrating disciplinary inputs should be investigated and communicated effectively. The assessment of this category is based on four questions:

1. Are disciplinary insights or perspectives of two or more disciplines selected that are relevant for solving the main question?
2. Does the student use an integration method or strategy (*e.g.* model, metaphor, analogy) to bring together disciplinary insights?
3. Is there a sense of balance in the overall composition of the text regarding the integration of the disciplinary perspectives or insights which further improves the product?
    a. Every discipline receives the appropriate amount of attention in the product (relative attention should be based on the overall relevance of the discipline to solving the problem or answering the question).
4. Do the conclusions drawn by the student indicate that his/her understanding has been advanced by the integration of the disciplinary views?
    a. The text shows that the interdisciplinary integration was effective and aided in solving the main problem or answering the main question.

4. Critical awareness

This category assesses the student's capacity to employ a meta-disciplinary view on interdisciplinary work, and whether he/she clearly reflects on the disciplinary approaches. This assessment is guided by two questions:

1. Is there a clear awareness of the limitations and benefits of the chosen disciplinary input and interdisciplinary integration?
    a. The pros and cons of the used disciplines and integration are investigated and discussed.
2. Does the student exhibit self-reflection, *i.e.* is he/she aware of the limitations of his/her work and chosen approach?

Four assessment scales

Score of 1: Naïve interdisciplinary understanding

1. The goal is unclear,
2. It is unclear who the intended audience is,
3. Based on common (disciplinary) knowledge,
4. The student doesn't use disciplinary insights or knowledge,
5. Different disciplinary perspectives aren't distinguished, resulting in a lack of multi-disciplinary integration.

Score of 2: Novice interdisciplinary understanding

1. Nascent grasp of the nature of interdisciplinary academic work,
2. The product is mechanistic,
3. The product has a weak composition,
4. Disciplinary theories and concepts are presented as facts,
5. Misunderstandings are abundant,
6. The scope of the question is too broad, too narrow or not achievable.

Score of 3: Apprentice interdisciplinary understanding

1. The product has a clear and achievable goal,
2. The product is clearly intended for a multidisciplinary audience,
3. There is good use of disciplinary concepts and insights,
4. Disciplinary concepts and insights are supported with examples and reliable sources,
5. Integration is reached by use of a metaphor, conceptual framework, causal explanation or other integration method,
6. There are missed opportunities to strengthen the presented arguments,
7. The product contains unnecessary pieces of text.

Score of 4: Master interdisciplinary understanding

1. The product is creative,
2. The product doesn't contain unnecessary information,
3. The product contains sophisticated self-reflection,
4. The student exhibits a comfortable understanding of disciplinary foundations,
5. The product contains a strong interdisciplinary integration,
6. The product has a clear goal,
7. It is clear why an interdisciplinary approach was chosen,
8. The product introduces new insightful examples that support the disciplinary information,
9. The perspectives are integrated elegantly and coherently,
10. Opportunities to strengthen the provided arguments are recognized and taken.

Using concept maps to assess interdisciplinary integration of green engineering knowledge

Borrego et al. (2009). Advances in Engineering Education, 1(3), n3.

The authors tested whether the use of concept maps would help student improve the integration of their knowledge and if the maps can be used to assess this improvement. The advantage of concept maps is that they allow students to graphically link topics and visualize complex interconnections (Novak & Cañas, 2006). The authors argue that the multidimensional nature of the maps makes them especially useful in an interdisciplinary setting because interdisciplinary problem solving often requires students to make connections between different concepts and disciplines at once. In addition, they argue that concept maps will be an asset to interdisciplinary teaching and learning because they assess knowledge integration as well as interdisciplinary learning and development on the individual level (instead of the group level which is often the case in interdisciplinary assignments). It is important to assess individual skills because this can be an appropriate indicator on how well an individual will function in an interdisciplinary team.

Assessing concept maps

The authors took the holistic scoring method by Besterfield-Sacre *et al.* (2004) for concept maps for one discipline as a starting point to develop their own multidisciplinary scoring method. In their assessment method, Besterfield-Sacre *et al.* (2004) used comprehensiveness, organization and correctness as evaluation criteria. They also developed a rubric to help the assessment (Table 6), in which these criteria can be scored on a scale from 1 to 3. The authors applied this method to concept maps drawn at the start and at the end of an interdisciplinary course (Green Engineering, in which the students were provided with instructions on how to draw a concept map (appendix C1)). The maps were scored by faculty members from three different departments (materials science and engineering, biological systems engineering and green engineering) using the method and the rubric developed by Besterfield-Sacre *et al.* (2004). Each member assessed the map individually, after which the scorers came together and reached a consensus on the final score. These discussions were taped and later analyzed to adjust the disciplinary concept map assessment method to an interdisciplinary method. Overall, the students used more appropriate topics and showed a higher degree of integration (higher visual complexity) in the concept map at the end of the course (appendix C2). This suggests an increase in knowledge integration.

TABLE 7
Rubric developed by Besterfield-Sacre & Gerchak *et al.* (2004) to assess concept maps.

	1	2	3
Comprehensiveness – covering completely/ broadly	The map lacks subject definition; the knowledge is very simple and/or limited. Limited breadth of concepts (i.e. minimal coverage of coursework, little or no mention of employment, and/or lifelong learning). The map barely covers some of the qualities of the subject area.	The map has adequate subject definition but knowledge is limited in some areas (i.e. much of the coursework is mentioned but one or two of the main aspects are missing). Map suggests a somewhat narrow understanding of subject matter.	The map completely defines the subject area. The content lacks no more than one extension area (i.e. most of the relevant extension areas including lifelong learning, employment, people, etc. are mentioned).
Organization – to arrange by systematic planning and united effort	The map is arranged with concepts only linearly connected. There are few (or no) connections between the branches. Concepts are not well integrated.	The map has adequate organization with some within/ between branch connections. Some, but not complete, integration of branches is important. A few feedback loops may exist.	The map is well organized with concept integration and the use of feedback loops. Sophisticated branch structure and connectivity.

Correctness – conforming to or agree with fact, logic or known truth	The map is naïve and contains misconceptions about the subject area: inappropriate works or terms used. The map documents are inaccurate understanding of certain subject matter.	The map has few subject matter inaccuracies; most links are correct. There may be a few spelling and grammatical errors.	The map integrates concepts properly and reflects an accurate understanding of subject matter meaning little or no misconceptions, spelling or grammatical errors.

Analyzing the assessor's discussions

Borrego *et al.* (2009) reviewed the assessment process and found the following difficulties in applying this assessment method to an interdisciplinary subject:

1. Since an interdisciplinary topic will be assessed, the scorers usually have different backgrounds and are possibly familiar with different evaluation criteria,
    a. Interdisciplinary assessment is more difficult because different assessors don't share common ground and may have different assumptions, values and epistemic frameworks,
    b. The assessors involved in this analysis noted that they were indeed assessing the maps quite differently from each other.
2. Different backgrounds can also result in different levels of expertise with the interdisciplinary topic, which can result in the dominance of one assessor who is viewed as the expert by the others,
    a. The green engineering scorer, for example, seemed to take a more dominant role in the scoring process. He actively tried to shape the other scorers' views and scores on the maps.
3. Scorers from different disciplines might not all be equally invested in the process and the course, which can lower the robustness of the assessment. The most committed can become dominant in the process.

To prevent these problems, the authors propose the following selection and training procedures for assessors:

1. At the start of the scoring sessions, assessors should be asked to make their evaluation criteria clear and time should be allotted to discuss these criteria,
2. In selecting assessors, one should aim to find people who have roughly equal levels of expertise and understanding of the topic to prevent dominance of one or multiple assessors,
3. Strategies should be applied to ensure that the assessors have a stake in the outcome of the assessment. This should ensure roughly equal levels of commitment,
4. The presence of a person who can bridge perspectives, as well as increased interaction time, can improve interdisciplinary collaboration. This will help, for example to reach a consensus on what kind of work is considered "excellent", "average" or "poor".

At the end of the whole process, the scorers expressed their increased interest in using concept maps in their own courses. Judging from these results, Borrego *et al.* (2009) concluded that concept maps can be a valuable assessment tool for knowledge integration if disciplinary differences are taken into account in the process of assessor selection and training. Ultimately, interdisciplinary assessment is a form of interdisciplinary collaboration.

Assessing development of an interdisciplinary perspective in an undergraduate neuroscience course

Crisp & Muir (2012). Journal of Undergraduate Neuroscience Education, 10(2), A88.

To evaluate the development of an interdisciplinary perspective in students enrolled in an introductory neuroscience course, Crisp & Muir (2012) used two assessment methods:

1. *Students response to "What is neuroscience?"*

Students were asked to write a response to the question "What is neuroscience?" within ten minutes, both at the start and at the end of the neuroscience course. The responses were analyzed to find changes in the use of disciplinary and interdisciplinary terminology. The results showed that students' answers were increasingly sophisticated and longer and they used more interdisciplinary terminology. Furthermore, the authors found that the students' answers reflected their increasing awareness of the interdisciplinary character of neuroscience.

2. *Term–discipline relevance survey*

The students were further asked to complete an anonymous survey in which they had to select the disciplines they found relevant for 41 terms (for example, "electrode", "taste"). This survey was also administered at the beginning and at the end of the neuroscience course. At the end of the course, students associated the terms with more disciplines than at the start. The authors concluded that the students had become more aware of the connection and inter-relatedness of disciplines.

Both assessments were given at the start and the end of the course to see how students' interdisciplinary perspective developed over time. Overall, the authors found that students used more integrative terms in their response at the end of the course and showed and increasing awareness of the complexity of neuroscience, acknowledging that it relies on the knowledge of multiple disciplines. In addition, the results showed that both methods can be used to assess interdisciplinary development over time and to determine the effectiveness of a course in reaching its learning goals. The authors further argue that the presented methods can be easily adapted to suit a different field by adding and changing the terms used in the term-discipline relevance survey.

Interdisciplinary assessment in the 21st century

Drake & Reid (2017). Academic Exchange Quarterly, 21(1).

Drake & Reid conducted interviews with teachers and faculty members who develop interdisciplinary assignments in high schools (grades 7 & 8). These interviews showed that there are four interconnected themes that are important in assessment practices:

1. Increased depth and diversity in classroom assessment,
2. Increased efficiency in classroom assessment,
3. Deepening assessment literacy,
4. Challenge of reporting result to student.

The interviews also showed that teachers are overall very positive and happy with the interdisciplinary learning environment but still unsure about how to assess accurately and credibly. The authors argued that more (empirically based) research should aid in the development of better assessment methods for interdisciplinary assignments.

Four interconnected themes to consider regarding interdisciplinary assessments practices

1. *Increased depth and diversity in classroom assessment*
    1. Backward design of assignments and during curriculum development (i.e. first big ideas and interdisciplinary kills were identified, then teachers created rich summative assessment tasks and finally instructional activities were created that included embedded assessment),
    2. Interdisciplinary assignments give student the chance to demonstrate their knowledge and skills in several subjects as opposed to just one,
    3. Interdisciplinary assignments give students better support in demonstrating their knowledge and skills in general,
    4. Interdisciplinary assignments result in more student-teacher conferencing.

2. *Increased efficiency in classroom assessments*
    1. Interdisciplinary assignments provide teachers with the opportunity to assess expectations in more than one subject at once (for example, mathematics and biology),
    2. Increased efficiency in grading because one single task provides a mark for more than one subject area.

3. *Deepening assessment literacy*
    1. Integrated curriculum planning stimulates professional growth among teachers,
    2. Students get the opportunity to actively participate in the planning and development of assessment criteria for interdisciplinary assignments,
    3. There is more opportunity for peer- and self-reflection,
    4. Teachers can regularly meet with other teachers to clarify interdisciplinary assessment standards.

4. *Reporting as an assessment challenge.*
    1. Teachers can be unsure about how to report in a credible way that meets accountability requirements,
    2. Insecurity about interdisciplinary assignments meeting the curriculum standards and whether disciplinary knowledge, concepts and skills may be lost in interdisciplinary programs.

A framework for analyzing interdisciplinary tasks: implications for student learning and curricular design

Svoboda Gouvea et al. (2013). CBE—Life Sciences Education, 12(2), 187-205.

This framework for analyzing interdisciplinary tasks is an assessment method with three interaction levels developed by Svoboda Gouvea *et al.* (2013) based on Paxon's' work (1996). It measures the level of interaction between two disciplines within a task. Svoboda Gouvea *et al.* additionally identified learning objectives and assessed how well the different interaction levels supported these objectives. Each level of interaction between disciplines can thus be evaluated in its potential to support these interdisciplinary learning objectives. The three different levels are:

1. Superficial interaction,
2. Unidirectional interaction,
3. Bidirectional interaction.

Every level has the possibility to support interdisciplinary learning. Level 1 tasks are limited in their ways to support interdisciplinary learning objectives but can draw a students' attention to the possible connections between disciplines. This can, however, backfire and give students the idea that one discipline is inferior to the other. Level 2 tasks support the interdisciplinary learning objectives more successfully and make students aware of the possibility to apply one method in different contexts. This unidirectional interaction, however, still limits the degree of interdisciplinary learning and can give the incorrect idea that one discipline should adjust to the other. Level 3 tasks have the biggest potential to support interdisciplinary learning objectives as a result of their emphasis on the interaction between disciplines. Hence, the use of mainly level 3 tasks should aid in the improvement of interdisciplinary courses. These courses should result in students becoming adaptive experts rather than routine experts. A routine expert is consistent and effective in solving problems in specific situations. While an adaptive expert is equally able to do this, but has additionally developed an understanding of the meaning and purpose of the applied problem-solving strategy. Using this knowledge on the conceptual context, the adaptive expert is able to make an informed decision about the relevance and utility of a strategy, resulting in a higher flexibility to solve problems in different situations.

Three interaction levels

Level 1: Superficial interaction

1. Low degree of interaction between disciplines,
2. No substantial exchange of ideas and insights between disciplines,
3. No self-reflection,
4. Disbalance between disciplines within the task.

Level 2: One discipline impacts the other

1. One discipline influences the other in a substantial way,
2. Conceptual reasoning strategies of one discipline are applied to the other discipline.

Level 3: Exploring connections between the disciplines

1. Meaningful, substantial and bidirectional interaction that effects both disciplines,
2. Substantial exchange of ideas, insights and knowledge,
3. The focus is on the interaction between disciplines, neither of the disciplines is dominant,
4. Differences and similarities of the working methods of the disciplines are explored,
5. Results in a better understanding of the differences and similarities between both disciplines.

Interdisciplinary learning objectives

A. Developing better conceptual coherence.
    1. Students can connect disciplinary concepts,
    2. Students can think about a subject outside their own discipline,
    3. Students can easily make connections,
    4. Students have a better conceptual framework.
B. Developing a varied set of scientific reasoning strategies.
    1. Students have knowledge on different reasoning strategies from different disciplines,
    2. Students know the differences and similarities between different reasoning strategies from different disciplines,
    3. Students can apply different reasoning strategies from different disciplines.
C. Developing metacognition and adaptive interdisciplinary expertise.
    1. Students know how and when different concepts and reasoning strategies should be applied,
    2. Students can reflect on their own actions and make adjustments where necessary.
D. Shifting students' attitudes and expectations about the disciplines.
    1. Students develop a new understanding and interest in disciplines outside their major,
    2. Misunderstandings in and about disciplines are abolished.

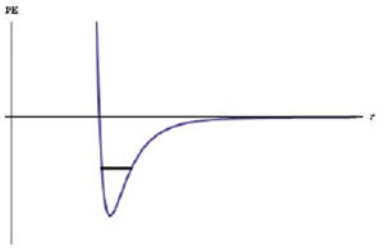
BOX 3
Examples of level 3 assignments

In their article, Svoboda Gouvea *et al.* (2013) gave multiple examples of level 3 assignments. As stated above, these assignments would best support interdisciplinary learning objectives. Below three of these assignments are shortly shown.

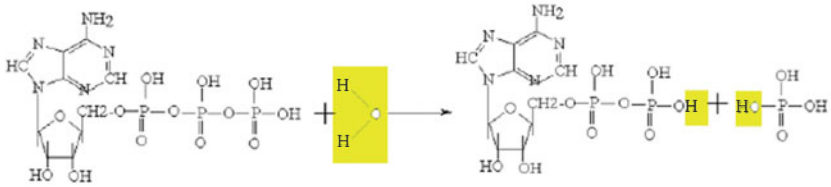
1. Essay questions that probe the understanding of a certain subject based on two statements that represent the knowledge and perspectives from two disciplines. Students must compare these statements and identify their strengths and weaknesses, as well as how they complement each other and make sense together. It is important that neither of the statements is privileged. Svoboda Gouvea *et al.* (2003) present an example question based on the physics and biology perspectives on ATP hydrolysis:

Two students, discussing the process of ATP hydrolysis (ATP + H2O à ADP + Pi), made the following comments:

Justin: "The O-P bond in ATP is called a 'high-energy bond' because the energy released when ATP is hydrolyzed is large. That released energy can be used to do useful things in the body that require energy, like making a muscle contract".
Kim: "I thought chemical bonds like the O-P bond in ATP could be modeled by a potential energy curve like this (she draws the picture above right), where the x-axis (r) is the distance between the O and the P. If that's the case, then breaking the O-P bond in ATP would require me to input much energy to break it, if that O-P happens to be a weak bond, but shouldn't if I have to input at least some energy?"



How did Kim infer from the potential energy graph that breaking the O-P bond requires an input from energy? If she's right that it does, how can you reconcile this with Justin's claim that ATP hydrolysis releases a lot of energy? (The chemical structures of this process are given if you find that useful).



adenosine triphosphate (ATP) adenosine diphosphate (ADP)

Note: This is an essay question. Your answer will be judged not solely on its correctness, but for its depth, coherence, and clarity.

2. Using different conceptual frameworks of multiple disciplines to solve a problem and in doing so discussing how and why the frameworks are different and similar.

3. Bringing the methodological choices and/or assumptions of different disciplines together and create an opportunity to examine them.

Meeting the challenge of interdisciplinary assessment

Olcese et al. (2014). Science education and civic engagement, 6:2.

The authors first conducted an analysis on the current state of interdisciplinary education and, based upon their findings, drafted an adaptable, multi-functional interdisciplinary rubric which was implemented at the United States Military Academy (USMA).

Firstly, in their analysis Olcese *et al*. (2014) noted that there is no agreed-upon definition of interdisciplinary education, a deficit that resulted in inconsistent grading, teaching and learning. This also makes it difficult to define the skills and capacities a student with good interdisciplinary understanding should demonstrate. Hence, the authors think that agreeing on one definition of interdisciplinary education should aid in creating a framework for interdisciplinary learning which includes the skills and capacities a good interdisciplinary student should have. To further explore these skills, Olcese *et al.* (2014) used the three interrelated criteria defined by Boix Mansilla & Duraising (2007) - disciplinary grounding, advancement through integration and critical awareness – to assess students' interdisciplinary work (Table 8). These criteria were used to set up basic learning objectives for interdisciplinary learning and to draft the grading rubric.

The authors also noted that it is impossible to set up an interdisciplinary program without cooperation across different disciplines. Programs need to communicate, share knowledge, create linkages and enhance coherence within and across the curriculum. Furthermore, faculties should strive to integrate interdisciplinary efforts because interdisciplinarity results in and breeds innovation.

TABLE 8
Three core dimensions of student interdisciplinary learning;
disciplinary grounding, advancement through integration and critical awareness.
These core dimensions should be reflected in interdisciplinary student work
(from: Boix Mansilla & Duraising, 2007).

CORE DIMENSIONS OF INTERDISCIPLINARY LEARNING	EXPLANATION
Well-grounded in the disciplines	The works shows rigorous understanding and appropriate selection of some of the following: examples, findings, methods, and forms of communication
Critical awareness	The works is mindful of the purpose and means by which the disciplines have been brought together as well as the limitations of the contributing disciplines and integration in light of the aims of the work
Advancement through integration	The work demonstrates that the student has developed a new model, perspective, insight, or solution that could only have been possible by integrating more than one disciplinary lens.

Olcese *et al.* (2004) found that there is no useful existing framework for the assessment of interdisciplinary work. As a response, the authors set up a grading system for the United States Military Academy (USMA) which can be used in multiple assignments and different disciplines. They drafted a grading rubric (appendix B) with open areas for point allotment as well as weighing for each category, which allows teachers to divide the points in a way they see fit for the assignment. The rubric contains six core principles:

1. Problem framing and scope; the students' work has a clearly defined purpose,
2. Disciplinary knowledge; the student demonstrates subject knowledge and applies it correctly,

3. Integration of ideas; the student can come up with multi-dimensional, feasible, practical solutions rooted in multi-faceted and seamlessly connected ideas,
4. Clarity of purpose; the student demonstrates a clear understanding of the topic's breadth and depth with a defined purpose of investigation,
5. Reflection; the way the student connects ideas indicates reflection on the interconnectivity of disciplines and the importance of the issue,
6. Presentation principle; the student can present and communicate his/her findings using a suitable medium, proper tone, choice of words, spelling, grammar, *etc*.

Implementing the rubric

To implement the rubric the faculty members at USMA were first introduced and familiarized with the assessment method. They learned how to properly apply and grade students' work by using the rubric on example essays. The staff members were also introduced to common integration errors, such as:

- the "laundry list" (student is knowledgeable in multiple disciplines but explains them individually instead of integrating the knowledge),
- "tacked on at the end" (student goes in-depth on one discipline and then tacks on a very short part at the end mentioning other disciplines in an attempt to make the work interdisciplinary),
- "no real knowledge" (student has a lot of ideas but doesn't show that he/she has learned from or integrated disciplines and/or ideas).

Afterwards, when all faculty members felt comfortable using the rubric, the assessment method was applied in the curriculum with thus far positive feedback.

Assessing interdisciplinary learning outcomes

Repko (2008). Academic Exchange Quarterly, 12(3), 171

In "Assessing interdisciplinary learning outcomes", Repko analyzed the literature on interdisciplinary learning, assignments and assessments, subsequently identifying multiple learning objectives listed in various papers as well as the following four cognitive capacities concerning interdisciplinary learning:

1. Development and application of perspective-taking techniques,
2. Development of structural knowledge of problems appropriate to interdisciplinary inquiry,
3. Integration of conflicting insights from two or more disciplines,
4. Production of cognitive advancement or interdisciplinary understanding of a problem.

While defining the learning objectives it became clear to the author that the process of integration is essential for interdisciplinarity and interdisciplinary programs. Therefore, the development of good synthesis and integration skills should play a central role in interdisciplinary learning. Repko also acknowledged that certain learning objectives such as critical thinking are a disciplinary as well as interdisciplinary learning objective. In these cases, the learning objective should be defined in such a way that the development of the skill clearly demands an interdisciplinary view and attitude.

Interdisciplinary learning objectives

A. Newell *et al*. (1990)
   1. Sensitivity to ethical issues,
   2. Enlarged perspectives or horizons,
   3. Ability to synthesize or integrate,
   4. More creative, original or unconventional thinking,
   5. More humility or listening skills,
   6. Sensitivity to bias.

B. Field (1994)
   1. Tolerance of ambiguity or paradox,
   2. Critical thinking,
   3. A balance between subjective and objective thinking,
   4. An ability to demythologize experts,
   5. Increased empowerment.

C. Cornwell & Stoddard (2001)
   1. The ability to see new and different questions and issues,
   2. The ability to draw on multiple methods and knowledge sources to address problems.

Four interdisciplinary cognitive capacities

1. *Development and application of perspective-taking techniques*
   1. Understanding multiple perspectives to be able to solve a certain problem, including disciplinary-based viewpoints,
   2. Assembling new sets of potential solutions to a given problem.

2. *Development of structural knowledge of problems appropriate to interdisciplinary inquiry*
   1. Development of structural knowledge,
      a. Understanding of higher order relationships and organization of principles,
      b. Knowledge obtained from different knowledge domains or disciplines,
      c. The ability to critically view relationships between relevant disciplinary perspectives,
      d. Resulting in a better cognitive analysis of the core theme.

2. Obtaining declarative knowledge (factual information),
3. Obtaining procedural knowledge (process-based information),
4. Being able to use declarative and procedural knowledge to solve problems,
5. Forming a conceptual framework.
    a. Complex internalized organization of knowledge,
    b. Contains most relevant perspectives, concepts, ideas and methods of a discipline,
    c. Framework gives meaning and connects different perspectives, concepts, ideas and methods,
    d. Helps determine when and how a set of declarative facts should be applied to a particular situation.

3. *Integration of conflicting insights from two or more disciplines.*
    1. Enhanced capacity to integrate conflicting insights from two or more disciplines,
    2. Identification and blending of knowledge from relevant disciplines to produce a more comprehensive understanding of a particular problem.

4. *Development of cognitive advancement or interdisciplinary understanding of a problem*
    1. The ability to explain a phenomenon, solve a problem, produce a product or formulate a new question which would not have been possible by solely using the knowledge from one discipline, and which results in interdisciplinary understanding and/or cognitive advancement
    2. Underlain by four core premises.
        a. Built on a performance view of interdisciplinary understanding, in which the ability to utilize knowledge is more important than simply gaining knowledge,
        b. The interdisciplinary understanding stems from disciplinary expertise,
        c. The interdisciplinary understanding results from integration of disciplinary perspectives,
        d. The interdisciplinary understanding is purposeful and results in cognitive advancement such as the explanation of a phenomenon, production of a product, generation of new insights, raising new questions or offering an explanation.

For the assessment of interdisciplinary work and the development of the four cognitive capacities presented above the author proposed two assessment methods, which will be elaborated on:

1. *Entrance and exit survey*
    1. Administration of identical surveys at the start and end of a course,
    2. Students grade themselves on their ability to demonstrate each of the four cognitive capacities.

2. *Developing grading rubrics for each course*
    1. Establishing how each assignment addresses one or more of the cognitive capacities,
    2. Establishing the relative weight that should be assigned to the different learning outcomes,
    3. Every capacity should be tested at least twice in a course at different moments, so the scores can be compared to asses development.
    4. Rubrics should be based on previously defined learning objectives.

Interdisciplinary program assessment

Stowe & Eder (2002). Issues in Interdisciplinary Studies 20: 77-101.

In 1998 the Association for Integrative Studies (AIS) set up a task force to investigate the status of assessment within the interdisciplinary community and to offer suggestions on how to improve the use of assessment in this field. The present paper is the result of three and a half years of research conducted by this task force.

Assessment as a concept

The authors start with addressing some common problems encountered when setting up an assessment plan. They noted that assessment definitions can differ between universities (Palomba & Banta, 1999) and can thus also vary between interdisciplinary programs. The authors suggest Angelo's (1995) definition of assessment as a good starting point, especially for people with little experience in assessment. This definition reads as follows:

"Assessment is an ongoing process aimed at understanding and improving student learning. It involves making our expectations explicit and public; setting appropriate criteria and high standards for learning quality; systematically gathering, analyzing, and interpreting evidence to determine how well performance matches those expectations and standards; and using the resulting information to document, explain, and improve performance. When it is embedded effectively within larger institutional systems, assessment can help us focus our collective attention, examine our assumptions, and create a shared academic culture dedicated to assuring and improving the quality of higher education." (Angelo, 1995)

For those who are more experienced in assessment the authors concede that a shorter definition should suffice. They suggest the definition of Marchese (1994) (in Palomba & Banta, 1999): "Assessment is the systematic collection, review, and use of information about educational programs undertaken for the purpose of improving student learning and development". Stowe & Eder (2002) concluded that many different definitions of assessment are being used, that the matter is an ongoing discussion, and that any definition should, at the very least, emphasize "student learning improvement".

The authors then moved on to the difference between evaluation and assessment because the two are often confused with one and another. Generally speaking, when data is collected to improve teaching and learning, this is called assessment. In addition, there are two main classes of data collection in assessment; direct and indirect. For direct assessment evidence is collected about student learning and the learning environment (for example via exams, projects and portfolios). For indirect assessment data is gathered on how students feel about learning and their learning environment (for example via surveys, questionnaires and reflective essays). Both can lead to improvements in the curriculum or pedagogy, and, if this is the case, it is often referred to as formative assessment. If data are collected to make judgements it might usually involve qualification (worth and value) for tenure, continuation of a program, the level of funding or continuation of accreditation. Data for the purpose of evaluation are collected in a manner that summarizes an entity's qualities.

Specific recommendations for interdisciplinary assessment

The authors struggled to find a well-developed assessment plan in the interdisciplinary field. Historically, universities are organized into disciplinary units that have run effectively over a large timespan. This division has worked well for developing separate disciplines, but the authors realized that this structure works against interdisciplinarity. People often find it difficult to work across disciplinary boundaries and thus the development of interdisciplinary assessment has been lagging behind. Another problem is that interdisciplinarity is viewed as a complex skill that is seemingly not subject to the reductive processes of assessment; for instance, some people see certain interdisciplinary competencies, such as curiosity, creative thinking or life-long learning, as not assessable (Klein, 2002). The authors do not agree with this conclusion and think that assessors can draft assessment measures that will effectively assess these competencies.

Another common struggle for assessors lies in deciding at what level to assess (course, program or institutional). The authors found that faculty members often want to see evidence of deep learning in students, i.e. students who can use learned facts, apply them in new situations and independently find and apply missing facts. For this to be the case, the authors emphasize that multiple factors need to be present in the collegiate environment. Some examples are:

1. Students must not solely be subjected to passive lectures,
2. Students must solve problems in which their discipline and knowledge is necessary, but which they can't solve without the input from different disciplines,
3. Students must encounter situations that will show them the importance of acquiring facts outside of their own discipline and inserting them into a new context,
4. Students must practice acquiring and manipulating facts in new contexts under faculty supervision.

The authors further note that deep learning is not accomplished in one course alone and thus should be assessed at the program, departmental or institutional level. They conclude that interdisciplinary learning is by its very nature deep learning, thus interdisciplinary assessment should also occur at levels above individual courses.

The authors also emphasize that in interdisciplinary assessment, both indirect and direct data should be collected periodically. This ensures that learning is taking place and shows whether adjustments need to be made to the program. As mentioned in the previous section, indirect data can be collected by asking students to reflect on their own learning. Direct data are created when students show their knowledge, skills and attitudes in carefully designed tests or situations. These could be complex assignments, internships, projects and real-world problems. Assessors more often use this direct kind of assessment, also called performance assessment, in interdisciplinary teaching because it requires students to show their skills in a way that is more in line with the interdisciplinary mindset, as compared to classic written exam (Palomba & Banta, 1999). Wiggins (1998) set up the following requirements for performance assessment:

1. Be realistic,
2. Require judgement and innovation,
3. Require students to perform in the subject,
4. Replicate real-life contexts,
5. Assess students' ability to efficiently and effectively use a range of knowledge and skills to negotiate a complex real-life task,
6. Allow some opportunity for the students to rehearse, practice, and receive feedback on their performance.

Stowe & Eder (2002) further advise to develop rubrics for performance assessment to clarify for both the assessor and the assessed what is intended and expected. The authors give the following reasons why these rubrics should be developed:

1. They are particularly useful in assessing complex intellectual processes,
2. They promote objectivity, reliability and validity in assessment,
3. They clearly specify what the student is expected to learn,
4. They clearly specify what is to be taught,
5. They provide opportunities for assessment in the course of the semester, thus allowing adjustments to be made,
6. They provide useful information on teaching and learning.

Steps to consider before drafting an assessment plan

Stowe & Eder (2002) emphasize that in the early stages of developing an assessment plan it might be useful to focus on a more linear outcome-oriented assessment approach, without acknowledging the complexity of interdisciplinarity. This should aid in clearly defining the main goal and learning objectives of the interdisciplinary studies (IDS) program. Such clarity is necessary because the goals of interdisciplinary programs are often not well defined, making it increasingly hard to set up an effective assessment plan. Hence, in this early stage Stowe & Eder (2002) emphasize that the following questions should be answered before starting to draft a more complex assessment model:

1. What is the mission of the IDS program? For whom and why does the program exist?

2. What are the major goals of the IDS program? What should a student be able to know, feel, think, and do after completing the program?
3. What are specific objectives of the program? What are measurable indications that the designated goals are being achieved?
4. What data will be collected, and how, to see whether the designated goals/objectives are being achieved?
5. When will these data be collected?
6. What will be done with these data?

If someone cannot answer basic questions such as who the intended audience is, how learning will take place and what the result of the program should be, the authors find it unlikely that an effective assessment plan will be developed.

Thinking about how students will be taught also forces the developers to critically investigate what "interdisciplinary" means and to set up explicit learning objectives. During this process, developers should realize that there is an overlap between disciplinary and interdisciplinary learning objectives. The authors acknowledge this but emphasize that even though interdisciplinary objectives are sometimes grounded in disciplinary objectives, overall, they are more complex. The authors divide the interdisciplinary learning objectives in three classes:

1. **Cognitive outcomes**; for example, critical thinking, creative thinking, awareness of biases, problem solving and the ability to synthesize or integrate disciplinary insights to construct a more comprehensive perspective (Newell, 1998),
2. **Affective outcomes**; for example, increased self-confidence, respect for differences and the ability to work in a multidisciplinary team,
3. **Developmental outcomes**; for example, moral and ethical development and progression through a series of developmental stages to a theoretically defined apex indicated as self-authorship (Baxter-Magolda, 2001).

Stowe & Eder (2002) see synthesis and integration as the objectives that are most often looked for in interdisciplinary assessment. As they note, these are difficult competencies that might have to be assessed by professional judgement (see next section) or via assessing multiple indicators of synthesis. If the answers to the above-mentioned questions are established, one can move to a more non-linear approach in which descriptive and goal-free assessment should be included.

Astin's outcomes-only model

As mentioned before, while drafting a simpler model for assessment one can start with gathering data on just a few major learning objectives. During this phase, Stowe & Eder (2002) advise to use Astin's (1993) outcomes-only model, which is based upon three interrelated concepts:

1. Input; anything related to the learner (for example, age, gender, socio-economic status),
2. Environment; complex field that combines philosophy, content, curriculum and pedagogy,
1. Outcomes; both intended and unintended results at the cultural, institutional, program, and course level.
    a. Cultural outcomes include ideals such as citizenship, confidence and character,
    b. Institutional outcomes must be assessed in coherence with the end goal of the program and can vary from retention to graduation,
    c. Programmatic outcomes focus explicitly on the learning objectives.

The model builds on the idea that learning objectives must be understood in terms of the learner's characteristics and the elements of the environment in which learning takes place, while focusing mainly on the curriculum and pedagogy. Astin (1993) recognizes that learning and teaching vary from time to time and that it is hence not enough to constantly apply only one part of the model during assessment. In this light, he proposes to use one of the following incomplete assessment designs at any given time to improve teaching and learning:

1. Outcomes-only assessment,
2. Environment-outcomes assessment,
3. Input-outcomes assessment,
4. Environment-only assessment.

Stowe & Eder (2002) add to this that due to the lack of appropriate assessment methods in interdisciplinary studies one should start with the outcomes component of the model and later work with the more difficult models (including input and environment).

Plan for developing a more complex interdisciplinary assessment method

In setting up a more complex interdisciplinary assessment method the authors underline five methods that should be included. These perspectives are mentioned below and summarized in Table 9.

1. Assessment by measurement; the program has measurable learning outcomes which can be assessed in a reliable and valid manner,
2. Assessment by objectives; a less rigorous data collection approach to enhance learning than is assessment by measurement. Active participation of faculty members and students in defining learning objectives is preferred,
3. Assessment by professional judgement; emphasis on experience, judgement and intuition in which the assessor is a skilled questioner. No data are collected since there are no objective criteria. This perspective may function best in coherence with reflective scholarship and more objective techniques to add insights and depth which are not readily available by applying one perspective alone,
4. Assessment by questions; focusses on questions that stakeholders might find interesting (for example, "what have our students learned this year?" or "are there differences between the learning outcomes of our residential and commuting students?"),
5. Assessment by discovery; focusses on goal-free assessment (see below) and assesses unexpected learning outcomes, i.e. without significant expectation on what should be found.

The authors recommend, to allow for and include goal-free assessments once students are becoming more experienced in the interdisciplinary field. These assessments do not solely focus on intended outcomes but allow for the emergence of unintended outcomes. This kind of assessment is often in line with the goals of interdisciplinary programs.

TABLE 9
Summary of the five perspectives to be included in an interdisciplinary assessment method.

	ASSESSMENT BY MEASUREMENT	ASSESSMENT BY OBJECTIVES	ASSESSMENT BY PROFESSIONAL JUDGMENT	ASSESSMENT BY QUESTION (DESCRIPTIVE)	ASSESSMENT BY DISCOVERY (GOAL-FREE)
Attributes	▪ Formal ▪ Systematic ▪ Emphasis on reliability, validity, and norms ▪ Analytic ▪ Emphasizes data and instruments	▪ Focus on intended outcomes ▪ Analytic	▪ Emphasis on experience and judgment ▪ Holistic	▪ Focus on questions of importance to faculty and students	▪ Goal-free
Strengths	▪ Objectivity ▪ Availability of instruments	▪ Stakeholders involved in reaching consensus on intended outcomes before instruction begins	▪ Offers access to complex outcomes	▪ Offers flexibility to stakeholders who desire assessment and are not comfortable with measurement	▪ Acknowledges potential for unexpected outcomes ▪ Validated intended outcomes
Weaknesses	▪ Focus on technical concerns/ process may negate the purpose of assessment ▪ Intimidating to those not trained in measurement	▪ Difficulty creating measurable outcomes for complex intellectual tasks.	▪ Subjectivity ▪ Observer bias	▪ Subjectivity ▪ Observer bias	▪ Subjectivity ▪ Observer bias
Data Collection	▪ Standardized instruments (both direct and indirect)	▪ Rubrics ▪ Performance criteria ▪ Observational protocols	▪ Informed opinion ▪ Rubrics ▪ Performance criteria	▪ Qualitative ▪ May be informed by quantitative data	▪ Qualitative

General comments on interdisciplinary assessment

The authors give several general comments based on theirs and other peoples' work on interdisciplinary assessment, which are summarized below:

1. Assessment and evaluation are not exactly the same thing,
2. External accountability activities (such as funding) should not influence the primary purpose of assessment, which is to improve learning and teaching,
3. The assessment of and in interdisciplinary programs should be a continuous, systematic process that results in data to help improve learning and teaching. Assessment is most effective if it is applied at key points and times in the curriculum (Field & Stowe, 2002),
4. Assessment of interdisciplinary programs should take place for a specific purpose, not out of necessity or based only on available techniques and tools,
5. Assessment of interdisciplinary programs is an ongoing process that requires active participation of all stakeholders who need to be equally committed to the improvement of teaching and learning in interdisciplinary studies.
6. Interdisciplinary assessment is most effective when it is developed locally with a clear goal and includes a variety of assessment methods which collect both direct and indirect data,
7. Performance tasks are essential for a comprehensive interdisciplinary assessment program (Eder, 2001).

Crossing boundaries: Steps toward measuring undergraduates' interdisciplinary science understanding

Tripp et al. (2020). CBE—Life Sciences Education, 19(1), ar8.

This paper, being a follow-up on the paper by Tripp & Shortlidge (2019), responds to the call to make interdisciplinarity a major part of life science majors. They emphasize that to do so successfully teachers must be able to assess interdisciplinary competencies. Therefore, the authors conducted three different studies. They wanted to investigate the current state of interdisciplinary assessment in science faculties, assess writing assignments by using a pre-existing rubric (developed by Boix Mansilla & Duraisingh *et al.*, 2009) and test whether students showed the same interdisciplinary understanding in their essays as during interviews.

Study 1

Tripp *et al.* (2020) started by determining the current state of interdisciplinary assessment in science faculties. They asked teachers and instructors via an online survey how they assess interdisciplinary competencies and students' interdisciplinary understanding, as well as how they define "interdisciplinary science". From the survey emerged that writing assignments are most commonly used to assess interdisciplinary competencies. Writing assignments ask students to explicitly identify similarities and differences between disciplines (jargon, methods and methodologies, concept and ideas), at the same time asking student to be critical of their own understanding (Connolly & Vilardi, 1989; Rivard 1994; Keys, 1999; Boix Mansilla *et al*., 2009; Balgopal *et al.,* 2012). Therefore, the authors agreed that writing assignments are a good way to test students' interdisciplinary understanding. Other methods that were mentioned often are traditional exams or quizzes and group work. Based on their findings, the authors developed a writing assignment in which students had to use their interdisciplinary understanding.

Study 2

The authors went on to assess the writing assignments they developed based on their findings in study 1, using a pre-existing rubric (developed by Boix Mansilla *et al.*, 2009). They did make some adaptations, leaving out criterion 3.2 because it did not fit the assignment, and merging criteria 4.1 and 4.2 because they were very similar and both students and assessors had a hard time distinguishing between the two. During the assignment it became clear that students needed more guidance on how to conceptualize interdisciplinary connections. Therefore, the students were given a shortened version of the rubric, which contained guiding questions (Table 10).

The same four-point scale was used that Boix Mansilla *et al.* (2009) used in their paper (1: naïve, 2: novice, 3: apprentice, 4: mastery) and then the average score for each construct was taken. This was necessary because not all elements contained the same amount of assessment criteria. The authors found the lowest scores were obtained in the constructs of integration and critical awareness, followed by disciplinary grounding and purposefulness.

TABLE 10
Adapted version of the rubric developed by Boix Mansilla *et al.* (2009), given to the students to help them in their interdisciplinary writing assignment.

RUBRIC ELEMENTS	CRITERIA	GUIDING QUESTIONS
Purposefulness	1.1	▪ Is there a clearly stated purpose that calls for an integrative approach and a clear rationale or justification for taking this approach?
	1.2	▪ Does the paper use the writing genre effectively to communicate with its intended audience?

Disciplinary grounding	2.1 2.2	▪ Does the paper use disciplinary knowledge accurately and effectively (e.g. concepts, perspectives, findings, examples, relevant & credible sources)? ▪ Does the paper use disciplinary methods accurately and effectively (e.g. experimental design)?
Integration	3.1 3.2b 3.3 3.4	▪ Does the paper include selected disciplinary perspectives and insights from two or more disciplinary traditions presented in the course or from elsewhere that are relevant to the paper's purpose? ▪ Is there an integrative device or strategy (i.e. metaphor or analogy)? ▪ Is there a sense of balance in the overall composition of the piece with regard to how disciplinary perspectives are brought together to advance the purpose of the piece? ▪ Do the conclusions drawn by the paper indicate that understanding has been advanced by the integration of disciplinary views (e.g. the paper takes full advantage of the opportunities presented by the integration of disciplinary insights to advance its intended purpose bot effectively & efficiently; integration may result in novel or unexpected insights)?
Critical awareness	4.1c 4.2c	▪ Does the paper exhibit awareness of the limitations and benefits of the contributing disciplines? ▪ Does the paper exhibit self-reflection (e.g, metacognition)?

b: Excluded from scoring
c: merged

After assessing the students' papers, the authors conducted multiple semi-structured interviews with some of the students to explore whether the rubric score matches students' verbal understanding of interdisciplinary science. If the rubric worked as intended, both the essay scores and interviews should give the same idea about a students' understanding of interdisciplinarity. The authors found some discrepancies between the interviews and essay scores. More than half of the students showed integration knowledge in their interviews but didn't do so in their essays. The same was found for the critical awareness construct. Thus, the authors concluded that the rubric did not fully capture students' interdisciplinary understanding and proposed that a framework might be more suitable for interdisciplinary assessment.

Study 3

The authors reassessed the interviews focusing on the full content of the answers instead of solely analyzing whether a student articulated a construct or not. This allowed the authors to test the robustness of the interdisciplinary framework criteria they articulated in their paper in 2019 (i.e. disciplinary grounding, different research methods, integration, collaboration and disciplinary humility). They found that many students emphasized the need for collaboration (thus displaying disciplinary humility) and the idea of integration was mentioned in every interview. However, the need to incorporate research methods was remarkably absent in almost all interviews. Overall, students' perceptions nevertheless reflected almost all the criteria of the interdisciplinary framework and the construct seemed to be working well, seeing that taken together, most students had similar scores for the essay and the interview.

Suggestions

Some findings especially caught the authors' attention, so they made some suggestions on how to deal with them:

1. Students who are taught to think and work interdisciplinarily should encounter a wide array of assignments suitable for their current interdisciplinary knowledge and skills.
2. Students who followed a course taught by instructors from different disciplines tended to have a higher overall score than students taught solely by one instructor. This might mean that students need to be actively exposed to interdisciplinary settings and need disciplinary knowledge to effectively integrate knowledge from different disciplines.
3. The biggest mismatch between essay and interview scores was found in the integration construct. The authors hypothesize that the current formulation of this element of the rubric may have led students to make simplified connections between disciplines. They think that the interdisciplinary framework could better support students to apply integrative knowledge.

4. Concerning critical awareness, a construct often missed in both essay and interview, the authors proposed that students should be aware of the strengths and limitations of the disciplines involved but it should not be expected that they identify all of them (which is currently asked in the rubric). Tripp *et al.* (2020) think it could be beneficial to reconstruct this criterion to let it match the criteria for disciplinary humility more closely. Students did express awareness of and respect for other disciplines and underlined the need for collaboration because of their own lack of knowledge.
5. Almost no students considered including non-STEM disciplines in their essay.
   It might be part of the instructors' role to make it clearer to students that non-STEM disciplines can be valuable in their research.

The National Academies of Sciences (2005) specifically highlights in its report this need, addressing life science majors: "Connections between biology and other scientific disciplines need to be developed and reinforced so that interdisciplinary thinking and work become second nature" (p.1).

From theory to practice: Gathering evidence for the validity of data collected with the Interdisciplinary Science Rubric (IDSR)

Tripp & Shortlidge (2020). CBE—Life Sciences Education, 19(3), ar33.

In order to measure undergraduate students' interdisciplinary science thinking, Tripp & Shortlidge (2020) developed an Interdisciplinary Science Rubric (IDSR). In previous papers , they focused on the development of an Interdisciplinary Science Framework (IDSF)(Tripp & Shortlidge, 2019) and they evaluated an often used interdisciplinary rubric developed for the Social Sciences and Humanities by Boix Mansilla *et al.* (2009) focused on "interdisciplinary understanding". They concluded that this rubric did not fully measure the assessment criteria from the IDSF with respect to the writing activities in science courses. Tripp & Shortlidge (2020) also reported that in terms of assessment, "understanding" is a nebulous term which is difficult or impossible to measure. They therefore indicated that interdisciplinary thinking is more accurate in describing the purpose of a rubric.

In addition they modified two other constructs used by Boix Mansilla *et al.* (2009) in their rubric (purposefulness and critical awareness were changed in: objective and broader awareness respectively, as shown below). With these modifications, Tripp & Shortlidge (2020) developed the IDSR and indicated that the newly proposed constructs are better able to measure a students' ability "to think in an interdisciplinary way when considering how to address real-world problems".

CONSTRUCTS IN RUBRIC FROM BOIX MANSILLA *ET AL.* (2009)	CONSTRUCTS IN RUBRIC (IDSR) FROM TRIPP & SHORTLIDGE (2020)
1. Purposefulness	1. Objective
2. Disciplinary Grounding	2. Disciplinary Grounding
3. Integration	3. Integration
4 Critical awareness	4. Broader awareness

This rubric (IDSR) was evaluated with an assessment of essays written by 102 students across five courses at three different institutions. These interdisciplinary essays on real-world problems were qualified with the IDSR. In addition they interviewed students as well as teachers/instructors on their experiences. From student interviews, they were able to confirm that both rubric & assignment assisted in thinking interdisciplinarily. Students indicated that it helped them to narrow the scope and expectations of the assignment, whereas the combination of rubric & assignment significantly improved students' perceptions and ability to think interdisciplinarily in science. Teachers indicated how to improve the rubric in order to obtain assessment scores that could be used to provide grades for the writing assignment. Based on these data, Tripp & Shortlidge (2020) further modified the IDSR in such a way that it should now be broadly useful across disciplines, both within and outside STEM (Science, Engineering, Technology and Mathematics).

In Table 11, the four categories and the different objectives per category from the IDSR are shown. The full Rubric can be found in the Appendix.

TABLE 11
The four categories plus objectives per category of the Interdisciplinary Science Rubric.

CATEGORY	OBJECTIVE
Objective	**1.1** **Purpose:** What is the problem and task? Provide background information to introduce and frame the problem/ task.
	1.2 **Approach:** How will you approach the problem/task? Formulate a plan that *clearly* outlines your approach (steps/procedure).
	1.3 **Credibility:** What sources will you include? Use peer-reviewed articles and/or other supporting information that are relevant to the problem/ task.
Disciplinary Grounding	**2.1** **Disciplines/ experts:** What disciplines and/or experts will be involved? Include *two or more disciplines and/or experts* in your approach to the problem/task.
	2.2 **Disciplinary reasoning:** Why are you including *each* discipline and/or expert? *Meaningfully* explain the reasoning behind the use of each discipline and/or expert.
	2.3 **Methods & Tools:** What methods will each discipline and/or expert use? Include techniques/ procedures/ tools from contributing disciplines and/or experts.
Integration	**3.1** **Leveraging Disciplines/ Experts:** How will each contributing discipline and/or expert *build off* one another to effectively address he problem/task in a way that one contributor cannot? Specifically address how each disciplines and/or expert's contribution *(knowledge/ methods)* will be useful for the other disciplines and/or experts.
	3.2 **Collaboration:** How will you foster successful partnerships? Include and explain two or more ways to build community and respect among different disciplinary team members (e.g. establishing common ground and language, overcoming different perspectives, etc.).
Broader Awareness	**4.1** **Social impact:** How does your proposed solution impact society? Include why your solution is locally and more broadly relevant to society and what/who will be affected (e.g. economics, politics, social, health, etc.).
	4.2 **Limitations:** What are the potential limitations to your plan and how will you overcome these barriers? Forecast possible limitations of your plan and provide resolutions.

Interdisciplinary writing assessment profiles

Wolfe & Haynes (2003). Issues in Interdisciplinary Studies, 21: 126-169.

The interdisciplinary writing assessment profiles (IWrAP) were developed by Wolfe & Haynes as an assessment method for interdisciplinary, research-based writing assignments. The authors drafted a rubric to analyze four dimensions of interdisciplinary writing:

1. Drawing on disciplinary sources,
2. Critical argumentation,
3. Multidisciplinary perspectives,
4. Interdisciplinary integration.

The first two dimensions assess elements that are used in disciplinary as well as interdisciplinary writing. The last two dimensions assess skills that are solely used in interdisciplinary writing. The student receives a grade for each element, which taken together result in a final grade for the whole assignment.

Wolfe & Haynes (2003) chose writing assignments specifically to assess interdisciplinary thinking and did so for three reasons. Firstly, writing assignments are frequently used in the curriculum of almost all disciplines. Secondly, writing assignments are one of the primary means of assessing learning in every discipline. It is a skill that is expected to be well developed in virtually every (inter)disciplinary setting. Finally, writing assignments result in fixed, concrete products (*e.g.* theses, articles) that can be used to indirectly asses dynamic mental processes such as synthesis, critical thinking, argumentation and integration.

The authors underline that assessors who want to use IWrAP need to have knowledge of interdisciplinary theories and general knowledge on the subject of the essay. They advise that two individuals independently asses the essay and thereafter discuss it, coming to a consensus on the final grade (interrater reliability). Furthermore, the assessors should first come to thoroughly understand the IWrAP assessment method, then read through the entire essay and finally reread the essay and grade the four dimensions and the final product. Every positive or negative judgement should be supported by at least one citation from the essay.

Four dimensions of interdisciplinary writing

1. Drawing on disciplinary sources

A. Positive source elements:
   1. Primary sources are used,
   2. At least 25% of the sources are recent publications, dated at least within the last 5 years of the project's completion,
   3. More than one perspective from at least one discipline is included.

B. Major negative source elements:
   1. Inappropriate sources are used (*e.g.* non-literary sources, noncredible sources),
   2. Sources are inappropriately used (*e.g.* misinterpretation, overextending),
   3. Overreliance on one or two sources (too many citations or concepts from one or two sources),
   4. Sources are quoted wrongly or out of context,
   5. Essential perspectives are missing, making it impossible to make a solid case.

C. Minor negative source elements:
   1. Product includes inappropriate quotations (which do not support the presented arguments; removal of the quotations significantly improves the text),
   2. Sources are paraphrased inappropriately,
   3. There is an overreliance on quotations (removal of the quotations improves the text),

4. Key contexts (as identified in the literature) are missing,
5. Not enough sources are included.

D. Scoring system for "drawing on disciplinary sources":
   - Score of 1 (student has serious problems with using disciplinary sources): Contains 1 or more of the major negative source elements, regardless of the number of positive source elements.
   - Score of 2 (student has no clue of the relevant literature, or has problems using the sources correctly): Contains 2 or more minor negative source elements, regardless of the number of positive source elements or contains 0 of the 3 positive source elements.
   - Score of 3 (student has a limited understanding of the use of disciplinary sources and struggles to use these sources accurately and effectively): Contains one of the 3 positive source elements and one of the minor negative source elements.
   - Score of 4 (student uses the sources only in a minor way or engages moderately but does not do so effectively or appropriately): Contains one of the 3 positive source elements and none of the negative source elements; or contains two of the 3 positive source elements and one of the minor negative source elements.
   - Score of 5 (student possesses an understanding of the primary and recent literature and is aware of the differing viewpoints on the topic in the used discipline(s)): Contains 3 positive source elements and one of the minor negative source elements.
   - Score of 6 (student has no major or minor problems concerning the use of disciplinary sources): Contains two of the 3 positive source elements and none of the negative source elements.
   - Score of 7 (student has a professional understanding with respect to drawing on disciplinary sources, conducted thorough research on the essay topic and used disciplinary sources effectively and appropriately): Contains all 3 of the positive source elements and none of the negative source elements.

2. Critical argumentation

A. Positive elements:
   1. The problem is clearly stated,
      a. The problem is well defined,
      b. The scope of the problem is clearly defined.
   2. Every major argument is supported,
      a. References to empirical evidence support the arguments,
      b. References to "textual" evidence (manuscripts, letters, current interpretations or critiques) support major arguments,
      c. Theories or theoretical principles support major arguments,
      d. Personal experiences or observations are used to support the arguments made (only applicable if the author has had considerable and relevant experience with the topic).
   3. The student reflects on the used approach,
      a. The student is aware of the limitations of his/her approach (the reflection should be at least one paragraph long),
      b. The student is aware of the strengths of his/her approach (the reflection should be at least one paragraph long).
   4. The student engages in meta-level analysis (analysis in a broad context).
      a. The student identifies limitations and shortcomings of at least one theory, perspective or disciplinary approach (the reflection should be at least one paragraph long).
      b. The student identifies merits of at least one theory, perspective or disciplinary approach (the reflection should be at least one paragraph long),
      c. The explanatory power of at least two theories is compared (the reflection should be at least one paragraph long).

B. Negative elements:
   1. There is evidence for misunderstandings of key concepts,
   2. The thesis is superficial or predictable,
   3. Irrelevant facts or arguments are presented (removal of the facts or arguments improves the text),
   4. Arguments are ordered illogically (a different order significantly improves the text),
   5. The text contains a significant amount of grammatical and mechanical errors,
   6. Ideas are presented in an inappropriate context,

7. Fallacious reasoning (*e.g.* conclusions are not based on the presented arguments, false analogy),
8. Analysis is underdeveloped or not enough in-depth,
9. The scope of the problem is too narrow or too broad.

C. Scoring system for "critical argumentation":
   - Score of 1 (student has major problems concerning critical argumentation and has not mastered basic writing skills): Contains none or one of the positive elements from one of the 4 categories regardless of the number of negative elements or contains more than 3 negative elements regardless of the number of positive elements.
   - Score of 2 (student has major problems concerning critical argumentation): Contains at least one positive element from 2 of the 4 categories and one or two negative elements.
   - Score of 3 (student has defined the problem and arguments but lacks critical reflection): Contains at least one positive element from 2 of the 4 categories and none of the negative elements.
   - Score of 4: Contains at least one positive element from 3 of the 4 categories and no more than one negative element.
   - Score of 5 (student shows good critical reflection): Contains a positive element from all the categories and no more than one negative element.
   - Score van 6 (student shows very good critical reflection and good writing skills): Contains at least one positive element from 3 of the 4 categories and no negative elements.
   - Score of 7 (student shows excellent critical reflection and very good writing skills): Contains a positive element from every category and no negative elements.

3. Multidisciplinary perspectives

A. Positive elements:
1. The student identifies a problem that can only be solved using an interdisciplinary approach,
2. The student demonstrates an understanding of how each discipline would approach the problem,
3. The student approaches the problem from multiple perspectives of different disciplines (the author uses at least one theory, paradigm or perspective taken from different disciplines),
4. The student identifies at least one term that is used differently in different disciplines in the context of the problem,
5. The student identifies how different disciplinary jargon is used to describe the same concept,
6. Sources are obtained from two or more disciplines.

B. Scoring system for "multidisciplinary perspectives":
   - Score of 1 (student only considers one discipline): Contains none of the positive elements.
   - Score of 2 (student considers more than one discipline, but only superficially): Contains 1 of the 6 positive elements.
   - Score of 3 (student considers more than one discipline): Contains 2 of the 6 positive elements.
   - Score of 4 (student shows average skills with respect to multidisciplinary perspectives): Contains 3 of the 6 positive elements.
   - Score of 5 (student shows good skills with respect to multidisciplinary perspectives): Contains 4 of the 6 positive elements.
   - Score of 6 (student shows very good skills with respect to multidisciplinary perspectives): Contains 5 of the 6 positive elements.
   - Score of 7 (student shows excellent skills with respect to multidisciplinary perspectives): Contains all 6 of the positive elements.

4. Interdisciplinary integration

A. Positive elements related to creating common ground:
1. The student reasons clearly why an interdisciplinary approach was used,
2. Assumptions of more than one discipline are presented and compared,
3. The student compares and makes the difference between disciplinary perspectives clear (student uses at least one theory, paradigm or perspective),
4. The problem is defined in neutral terms that encourage contributions from multiple disciplines (the student doesn't use disciplinary jargon),
5. The student creates a vocabulary that can be used by all disciplines that contribute to solving the problem.

B. Positive elements related to a new holistic understanding:
    1. One or more new analogies, metaphors or comparisons are presented that stimulate the reader to think about the subject in an interdisciplinary way,
    2. An existing analogy, metaphor or comparison is presented or applied in a novel way which stimulates the reader to think about the subject in an interdisciplinary way,
    3. One or more new models are presented that stimulate the reader to think about the subject in an interdisciplinary way,
    4. An existing model is presented or applied in a novel way that stimulates the reader to think about the subject in an interdisciplinary way,
    5. A new theoretical interpretation or understanding is presented which could only have been established through the collaboration of multiple disciplines.
C. Positive elements related to the application of the new holistic understanding:
    NB: If no credit was given for the category interdisciplinary integration part B (new holistic understanding) then credit is only possible for the last element in the application of the new holistic understanding category (element 6, interdisciplinary theory).
    1. The new metaphor, interpretation or model is applied to a new situation or phenomenon and the impact of this is explicitly discussed,
    2. The new metaphor, interpretation or model is applied in a novel way on an existing text, situation or phenomenon and the impact of this is explicitly discussed,
    3. The new metaphor, interpretation or model is extensively tested through observation, data collection, or lived experience and reflection on the strengths and weaknesses of the model are discussed in the light of empirical evidence,
    4. The new metaphor, interpretation or model results in new research and inquiries,
    5. The new metaphor, interpretation or model is tested by using it to solve a problem,
    6. One or multiple interdisciplinary theories are used to discuss the strengths and weaknesses of the chosen approach.
D. Scoring system for "interdisciplinary integration":
    1. Score of 1 (text contains no interdisciplinary integration or critical, self-conscious synthesis of two or multiple disciplines): Contains no elements from one of the 3 categories (creating common ground, new holistic understanding and application of the new holistic understanding).
    2. Score of 2 (text contains a weak interdisciplinary integration): Contains elements from just one of the 3 categories.
    3. Score of 3: Contains elements from 2 of the 3 categories.
    4. Score of 4 (student is a good holistic thinker but doesn't create clear common ground): Contains one of the 5 elements from the category "creating common ground", and at least one element from the categories "new holistic understanding" and "application of the new holistic understanding".
    5. Score of 5 (text contains a good interdisciplinary integration, the student creates a new holistic understanding and applies this to the chosen subject): Contains 2 of the 5 elements from the category "creating common ground", and at least one element from the categories "new holistic understanding" and "application of the new holistic understanding".
    6. Score of 6 (text contains a very good interdisciplinary integration, the student creates a new holistic understanding and applies this to the chosen subject): Contains 3 of the 5 elements from the category "creating common ground", and at least one element from the categories "new holistic understanding" and "application of the new holistic understanding".
    7. Score of 7 (text contains an excellent interdisciplinary integration, the student creates a new holistic understanding and applies this to the chosen subject): Contains 4 of the 5 elements from the category "creating common ground", and at least one element from the categories "new holistic understanding" and "application of the new holistic understanding".

Limitations of IWrAP

The authors realized there were limitations to their assessment method, namely:

1. It was only tested on essays that were 55 pages or longer,
2. It was not easily usable as a result of the large quantity of categories.

Assessing students' disciplinary and interdisciplinary understanding of global carbon cycling

You et al. (2018). Journal of Research in Science Teaching, 55(3): 377-398.

You *et al.* (2018) validated the interdisciplinary science assessment of carbon cycling (ISACC) and reported on the empirical results of their study conducted with high school and undergraduate students, including an analysis of the relationship between interdisciplinary and disciplinary items. The research focus was directed at the students' understanding of the interdisciplinary topic of carbon cycling. Furthermore, the authors assessed the requirements for developing a measure for interdisciplinary understanding and what the advantages are of interdisciplinary teaching.

The analysis of the participants' interdisciplinary capacities showed that interdisciplinary and disciplinary understanding are strongly correlated. More specifically, it showed that students use their disciplinary knowledge to develop interdisciplinary understanding. This suggests that it may not be possible to have an interdisciplinary understanding of a topic without disciplinary knowledge, hence students should only start working on interdisciplinary problems when they have gathered enough disciplinary knowledge. Further support for this view is the fact that in order to solve an interdisciplinary problem or gain cognitive advancement, it is necessary to integrate knowledge from two or more disciplines. Thus, students will do better on interdisciplinary problems if they have more knowledge of the disciplines that are to be integrated. With that in mind, the authors noted that it is important for assessors to establish whether a students' inability to solve an interdisciplinary problem stems from a lack of disciplinary knowledge.

D Discussion & Conclusion

Discussion

Practicing interdisciplinary thinking and collaboration is essential to prepare (disciplinary) students for the increasingly interdisciplinary nature of research and to achieve solutions for the complex problems the world is facing. In this report we consecutively examined what interdisciplinarity encompasses, what competencies are required and then showed how interdisciplinary competencies can be assessed, drawing from a variety of articles. All along, this overview also aimed to shed light on some of the difficulties that accompany interdisciplinarity education, teaching and assessment. It can already be stated in advance that there is no one optimal strategy, assignment or assessment to develop and evaluate interdisciplinary competencies. Based on this overview, it has become clear that the context in which interdisciplinary education takes place is of crucial importance to those matters.

Define interdisciplinarity

One of the observations and possible problems emerging from the literature is that interdisciplinarity is still not clearly defined. This lack of a unified definition can result in confusion which researchers, teachers, students and other individuals working in an interdisciplinary context may experience in a field that already tends to be seen as abstract and complex. This in turn can result in a negative bias towards interdisciplinarity by faculties as well as an apprehension to its inclusion in the (disciplinary) curriculum.

Ideally then, there should be one agreed-upon definition that reflects the current view on interdisciplinarity in the educational field. Such a workable definition that is applicable in all disciplines will render interdisciplinarity less abstract and can therefore facilitate consistent teaching, learning and assessment. It can do so by helping to clearly define learning objectives and develop corresponding education programs. In addition, it will prevent confusion as to what exactly 'interdisciplinarity' means and thus reduce some of the reservation faculties may have when it comes to supporting interdisciplinary education and teaching.

In addition, it is important to realize that interdisciplinarity is also a process rather than an outcome only. In this interdisciplinary process towards obtaining an interdisciplinary product or solution, distinctions between concepts like 'transdisciplinarity' or 'multidisciplinarity' may become less relevant as the perspectives of different disciplines (multidisciplinarity) and/or the non-academic context (transdisciplinarity) always need to be included before an interdisciplinary solution to a complex problem can be achieved.

Two closely related definitions for interdisciplinarity currently stand out: The one established by Boix Mansilla *et al.* (2009) is the most frequently used and emphasizes **interdisciplinary understanding** as "the skill to integrate knowledge and modes of thinking from two or more disciplines which results in a cognitive advancement, such as the explanation of a phenomenon, solving a problem or producing a product, which would not have been possible if solely the knowledge of one discipline had been used". The definition recently proposed by Tripp & Shortlidge (2019), although based on the definition of Boix Mansilla *et al.* (2009), aims to cover the idea of **interdisciplinary working & thinking** within the sciences: "interdisciplinary science is the collaborative process of integrating knowledge/expertise from trained individuals of two or more disciplines – leveraging various perspectives, approaches and research methods/methodologies – to provide advancement beyond the scope of one discipline's ability". We suggest that these definitions, although very comparable, emphasize differences between the scientific fields in which they are used (social sciences and humanities vs. natural sciences) as well as differences in the competencies addressed (interdisciplinary understanding vs interdisciplinary working & thinking). In this respect, Tripp & Shortlidge (2020) indicated that 'interdisciplinary understanding' is difficult

or even impossible to measure in contrast to the competency of 'interdisciplinary thinking'. By modifying two constructs (purposefulness and critical awareness) used in the rubric by Boix Mansilla *et al.* (2009) into 'objective' and 'broader awareness' respectively, Tripp & Shortlidge (2020) showed that these new constructs are better able to measure a students' ability "to think in an interdisciplinary way when considering how to address real-world problems".

Until there is a general consensus with respect to a definition for 'interdisciplinarity', a fruitful approach is to focus on the commonalities of the definitions currently in use, where two core concepts emerge as particularly important:

- Firstly, the integration of knowledge from at least two different disciplines is considered to be at the very heart of interdisciplinarity. Before such integration can be achieved, perspectives from multiple disciplines have to be analysed and common ground created.
- Secondly, this integration should result in the attainment of some sort of product, for example new knowledge, solutions or views, that could not have been acquired if knowledge and methods of only one discipline had been used. According to the definition by Trip & Shortlidge (2019) the word 'leveraging' reflects that the resulting product or solution may have emergent characteristics or properties (an emergent property is a property which a complex system or collection of members has, but which the individual members do not have).

The above-mentioned commonalities can be used to design both the teaching strategies as well as the assessment of interdisciplinary competencies.

Competencies

In order to work efficiently in multi-disciplinary teams, students should master certain competencies. These competencies reflect the interdisciplinary knowledge, skills and attitudes a student needs to succeed in an interdisciplinary setting. In the papers summarised and discussed in this report, these competencies are often set up like a walkthrough of the interdisciplinary process, starting with gaining disciplinary grounding and appreciation of disciplinary strengths and shortcomings, followed by creating common ground and integration of various perspectives, eventually leading to a formulation of a coherent and useable interdisciplinary product. As indicated before, a consensus on what interdisciplinarity is and which learning objectives and competencies are intertwined with this definition should aid in developing a coherent interdisciplinary teaching program which can be administered in various faculties within the same university or even in various universities.

The literature on interdisciplinarity is ever increasing and a large number of potential interdisciplinary competencies have been suggested. Some of these competencies are, however, tested on a specific set of students embedded in a disciplinary context, *e.g.* students within the social sciences or with an engineering degree, and/or been validated in one specific test setting. It remains to be questioned how well such findings generalize to different students and different settings. In addition, there are papers that describe adapted versions of previously reported competencies, making the list of potential interdisciplinary competencies longer and possibly overwhelming. To avoid unnecessary extensiveness and aim at a more concise list of relevant competencies, we can again look at similarities between them. We will do this in relation to the two main concepts in the definition of interdisciplinarity as have been summarized in the bullet points above.

Integration of knowledge

The first concept focusses on drawing and integrating knowledge from at least two different disciplines or sources. Since students must use disciplinary knowledge to ultimately produce an interdisciplinary product, they should first acquire a certain level of disciplinary grounding in their curriculum. This doesn't mean that a student must be an expert in every discipline he/she is trying to integrate. Quite the opposite might be true: trying to become an expert in two or more disciplines often results in shallowness of proficiency in each of the disciplines and may reduce the potential for successful interdisciplinary collaboration. Apart from being (firmly) grounded in one discipline, it is often expressed that one should also have a certain level of knowledge of concepts, assumptions and research methods used in one or more other disciplines. Since interdisciplinary work, especially in the sciences, leans on the collaborative ability of experts from different disciplines, this abolishes the need to be an expert in all fields. However, this emphasizes the importance of educating students not only as disciplinary experts but also as openminded researchers able to cooperate in multidisciplinary teams who

know how to find interdisciplinary solutions for the complex problems they are working on. This teamwork ability requires knowledge of what a discipline entails, its strengths, but also its limitations. In this respect, the concept 'disciplinary humility' is often mentioned, which reflects the awareness that one discipline alone is not enough to solve complex problems, that other disciplinary perspectives are equally valuable and necessary to achieve efficient and workable solutions. This concept or attitude of disciplinary humility is one of the five core criteria of the framework for interdisciplinary education as proposed by Tripp & Shortlidge (2019). Students should therefore learn to appreciate different disciplinary perspectives and reflect on how different disciplines relate to and complement one another. Students must also be able to clearly articulate why selected disciplines were included in a research project, why others were excluded and what information and methodologies were used. This includes learning how to make connections between different disciplines and the ability to formulate common ground, to redefine specific issues, thereby bridging seemingly unbridgeable differences. In all this, communication is crucial. Hence, students should not only be able to discuss their ideas with fellow disciplinary students using their shared jargon, but they should also be able to explain their disciplinary ideas in accessible jargon-free language, understandable for participants from other disciplines. Currently, students often do not get the chance to explore and understand significant differences or similarities between disciplines, which can seriously hamper any interdisciplinary process they will participate in as future disciplinary experts.

Within many multi-disciplinary curricula to date, it is by and large left to students to make connections between disciplines and integrate ideas when working in an interdisciplinary setting during their (under)graduate program. Without appropriate preparation, such efforts usually result in fragmented conceptions (Linn *et al.* 2016). It is the task of higher education to teach students how to integrate knowledge from different disciplines, so they can formulate coherent solutions for the complex real-world problems we are facing today (Linn *et al.*, 2006; Shen & Linn, 2011). Thus far, disciplinary education often is not adequately attuned to train the required competencies which can help the students to understand how different disciplines relate to one another when working on the same problem (Ivanitskaya *et al.*, 2002). Fortunately, there is an increased awareness currently that higher education needs to address the training of interdisciplinary competencies, include 'interdisciplinarity' as learning goal in their disciplinary curricula and to underscore some of the positive aspects of interdisciplinarity.

Attainment of an interdisciplinary product

The second concept that is central to the definition of interdisciplinarity focusses on the result of interdisciplinary collaboration, the achievement of which would not have been possible by relying on one discipline alone. This concept builds on adequately executing everything that comes with the first core concept and, in addition, explaining to students the (emergent) value of interdisciplinary collaboration outcomes as compared to disciplinary ones. It should be mentioned that the need for such explanation may differ between departments, seeing that in the social sciences and especially in the sciences it is already more common to find collaborative efforts between multiple disciplines. Until recently, this was less customary in the humanities. Furthermore, students should be made aware that creativity, unconventional thinking, adaptability, tolerance of ambiguity and being able to think outside the box are inextricably intertwined with interdisciplinarity.

Similarities between the two concepts

There is some overlap in the required knowledge, skills and attitudes following from the first and second core concept, as discussed above. Examples of this overlap are respect towards others and other disciplines, being aware of one's own biases and being able to reflect on one's own work. An important skill that is required in both concepts is the ability to effectively collaborate and communicate with other disciplinarians in accessible, jargon-free language. When disciplinary education aims at adding the training of these competencies, students can develop to become valuable team members who successfully work within and beyond disciplinary boundaries. In this report we have summarized some articles that focused on training of the skills mentioned above. In the next section ("Towards interdisciplinary assessment") we will summarize the most important learning goals as well as provide a list with frequently mentioned interdisciplinary competencies which are of relevance in relation to assessment purposes in interdisciplinary education.

Towards interdisciplinary assessment

Competencies should not only be defined and practiced through appropriate assignments during a course or curriculum, they should also be assessed effectively. To date, a generalised assessment method for interdisciplinary assignments, courses and/or programs has not yet been developed. This is partly due to the lack of empirical research into interdisciplinary assessment methods (Boix Mansilla *et al.* 2009; Tripp & Shortlidge, 2020), partly due to the absence of a cognitive model of interdisciplinary understanding (Boix Mansilla, 2005). Additionally, most of the currently applied methods focus on a specific (disciplinary) group of students usually involved in writing assignments. This results in assessment methods that are biased towards a certain group of students (social sciences, humanities or sciences) and a lack of assessment methods for assignments other than writing tasks. To achieve a high standard of interdisciplinary education, it is important to take a systemic approach concerning the formulation of learning goals, assignments focused on practicing specific interdisciplinary skills and the assessment of interdisciplinary learning. This should result in the development of programs with effective assignments and assessment methods. Not only will such improved assessment support students in attaining interdisciplinary learning goals, but it will also give teachers and faculties a tool for quality control to make sure (inter)disciplinary standards are met.

Besides the shortage of studies suited for generalization, an additional problem in the development of appropriate assessment methods is that assessors usually come from different disciplinary fields and may not have much experience with interdisciplinary assessment. It is all the more important to educate assessors, because if not addressed properly, their assessment might be biased by their disciplinary knowledge and assessment methods. In part, this problem can be resolved by discussing assessment standards and rubrics before their implementation and making sure that all assessors have roughly equal levels of expertise. This means that teachers and faculty staff need to be informed on what interdisciplinary assessment entails.

As previously argued, the first step in defining an appropriate interdisciplinary assessment method is to define clear learning goals and learning objectives, which should not only support teachers but also help students' efforts by raising awareness for what they will be evaluated on (Carmichael, 2016). Below, we will propose a set of learning goals and objectives based on what we encountered in the literature on interdisciplinary education. In addition, relevant competencies will be listed and relevant rubrics presented, which can be used for assessment purposes in interdisciplinary education.

Towards a matrix of rubrics for interdisciplinary assessment

Assessment usually takes place in the context of learning goals and objectives, which are used to design specific assignments aimed to develop the competencies mentioned in those learning goals. To establish a common practice for interdisciplinary assessment, it would be useful to agree upon a common set of learning goals. Therefore it is useful to start with an overview of the learning goals and objectives that are most often mentioned in regard to interdisciplinary education.

To clarify, the distinction between "learning goals" and "learning objectives" in this context is as follows: learning goals refer to the higher-order (abstract) ambitions for the students, while learning objectives are specific, measurable competencies which can be assessed to decide whether the desired learning goals have been met.

Learning goals: Although a wide variety of learning goals have been described in the literature of interdisciplinary higher education, many of them were overlapping rather than complementary, or merely phrased slightly differently, rather than making a crucial distinction. Below, we present what in our view are the four main learning goals in interdisciplinary education (Disciplinary grounding, Perspective taking, Finding common ground and Integration), together with a short explanation of the main competencies (skills, knowledge and/or attitudes) a student should exhibit upon achieving these learning goals (Table 12).

Learning objectives: Apart from the four learning goals, a variety of learning objectives for interdisciplinary learning have been formulated and described in many of the papers discussed in this report. Formulating the associated learning objectives is prerequisite to evaluating whether a student has reached the learning goals. Learning objectives can be focused on the obtainment of new knowledge, insights or skills. In Table 12, a number of learning objectives are formulated for each of the learning goals.

TABLE 12

The four main learning goals in interdisciplinary education

with a short description of the main learning objectives (resulting in skills, knowledge and/or attitudes of the student).

LEARNING GOAL	LEARNING OBJECTIVES (COMPETENCIES TO BE ACHIEVED)
1. Disciplinary grounding	▪ Having a good level of knowledge, understanding & insight in one's own discipline (including epistemology & common methodologies used). ▪ Being familiar with the common theories & concepts of a discipline. ▪ Ability to communicate within a discipline (including ability to use jargon). ▪ Recognition of the strengths, weaknesses & limitations of one's own discipline. ▪ Disciplinary humility (due to the realization that many complex problems cannot be solved without input from other disciplines, as well as the awareness that each discipline has its limitations).
2. Perspective taking	▪ Ability to explain the main perspective on a complex problem from the viewpoint of another discipline (to a multidisciplinary audience). ▪ Ability to communicate disciplinary knowledge to a multidisciplinary audience with accessible, jargon-free language. ▪ Being familiar with how knowledge & ideas from one's own discipline are distinctive from other disciplines (with regard to assumptions, values, methods, etc.). ▪ Respectful attitude towards other disciplines, combined with disciplinary humility (see above). ▪ Awareness of the gain of a richer and more comprehensive understanding when additional perspectives are considered. ▪ Intellectual curiosity, including an openness to unfamiliar arguments & premises. ▪ Alertness to relevant approaches of other team members and their disciplines.
3. Finding common ground	▪ Ability to identify commonalities, conflicts and discrepancies between disciplinary insights; dualistic thinking. ▪ Embracing contradictions and eagerness to ask how matters can be seen both ways; inclusive & unconventional thinking. ▪ Willingness and capacity to rephrase and adapt disciplinary concepts and ideas in order to create common ground. ▪ Ability to objectively reflect on the strengths and weaknesses of the chosen disciplinary perspectives. ▪ Tolerance of ambiguity & paradox (since a complex problem may have more than one good solution). ▪ Ability to focus on strengths in unfamiliar/uncomfortable arguments and weaknesses in familiar/comfortable ones when evaluating disciplinary insights.
4. Integration	▪ Ability to connect & integrate knowledge from different disciplines using multiple integration methods (conceptual frameworks, graphic presentations, metaphors, models, the methods defined by Newell and Repko, such as extension, redefinition, transformation and organization). ▪ Open mind and focus on gaining advancement through integration of disciplinary perspectives. Integration optimally results in a more comprehensive, effective and empirically grounded product (thereby showing a level of innovation and/or emergence) that could not have been achieved by only one of the disciplines. ▪ Capacity to integrate with cognitive advancement as a result. ▪ Showing **critical or broad awareness** (meta-disciplinary & meta-cognitive view), ability to reflect on the decisions made, such as: strength & weaknesses of the disciplinary perspectives, chosen disciplinary contributions, interdisciplinary approach, correctness of adjustments made to reach common ground, steps taken in the interdisciplinary integration process, compromises and limitations of the final product as well as the societal impact the final product or proposed solution may have).

Interdisciplinary competencies: In the literature, a variety of competencies is mentioned throughout different papers. A comprehensive list of required competencies to work and think effectively in the field of interdisciplinarity has, to our knowledge, not yet been published. The following (non-exhaustive) list may give an impression of the competencies most frequently mentioned in the literature. For a description of all these interdisciplinary competencies, see (Angerer *et al.* 2021):

- Creative
- Critical attitude
- Communicative & ability to communicate within and beyond one's own discipline
- Collaborative (ability to cooperate in a multidisciplinary team)

- Courageous & willingness to take risks
- Flexibility
- Intellectual curiosity
- Initiative for exchange
- Metacognition
- Patience
- Proactive
- Reflective disposition.
- Respect for & appreciation of other perspectives
- Rooting in one's own discipline
- Self-reflection & self-authorship
- Sensitivity to bias
- Tolerance for ambiguity & paradox

Matrix of rubrics for interdisciplinary competencies: After having elaborated on learning goals and required competencies it is time to focus on a tool which can be applied in multiple settings to support interdisciplinary assessment. Usually, a rubric focused on a specific interdisciplinary skill is used to clarify what quality of work students should produce on a novice, intermediate and expert level. Examples of rubrics for a writing assignment on an interdisciplinary topic are the ones by Boix Mansilla et al (2009) and by Tripp & Shortlidge (2020). A matrix, consisting of a number of interdisciplinary rubrics, could be useful to identify and focus on different skills in different settings. Such a matrix would be easily adaptable to a variety of assignments in which specific competencies are required and assessed. For both teachers and students alike, rubrics are useful tools: they can help teachers to design and assess specific assignments and students to clarify what is expected of them.

Based upon the articles discussed in this report, we have developed a matrix which consists of a number of rubrics. Each rubric focuses on a specific interdisciplinary learning goal or competency. For every category, we defined what insufficient (novice), sufficient/good (intermediate) and very good/excellent (mastery) work should look like. Every learning goal and competency can be assessed independently and is based on multiple requirements which are indicated in the rubric. The rubric can be used to assess what level students are currently operating on, what kind of assignments they can handle and in which competencies they can improve. With these rubrics at hand, teachers can more easily identify and aim at bridging possible gaps in the students' interdisciplinary development.

Judging from the vast variety of competencies, it may be obvious that not all of those listed in the matrix can be (or need to be) addressed in any single interdisciplinary assignment at once. The idea is that teachers can pick one or multiple specific learning goals and/or competencies they want to advance via a particular assignment. The rubric helps to identify what performance can be expected of the students depending on the choice of learning goals and/or competencies, and can hence be used not only to specify learning objectives during a course, but also to develop suitable assignments. Thus, the rubric can support teachers, students and the development of interdisciplinary assignments. Hopefully, it can also reduce some apprehension that teachers and faculties may have towards interdisciplinarity. The matrix of interdisciplinary rubrics is offered as a separate document, but can also be found in Appendix D.

Conclusion

It is an undisputed statement that interdisciplinary understanding is not only valuable for society's future welfare, but also for students themselves, and that it will be a great asset in their future careers. At the very least, integrative interdisciplinary learning allows students to develop a more holistic view of their academic environment, the strengths and limitations of their own discipline, the necessity to involve other disciplines to solve complex problems and hence a better ability to navigate the interdisciplinary field. At the very best it will result in students tackling the complex and urgent problems our society is facing by effectively collaborating with other interdisciplinarily oriented colleagues who are specialized in different disciplines.

To better prepare undergraduate students for the increasingly interdisciplinary nature of research and future work, it is necessary to offer students sufficient opportunities to develop interdisciplinary competencies as a part of their disciplinary education. However, devising suitable educational approaches requires a more unified understanding of interdisciplinary working and thinking. To better understand what this entails, we have analysed a variety of articles in the field ofn interdisciplinarity and interdisciplinary education and focused on common ground between definitions of interdisciplinarity, the competencies which are required and the various ways in which interdisciplinary knowledge and skills can be assessed.

Based on the findings summarized in this report, we can conclude that there are some commonalities across definitions that clarify what interdisciplinarity entails, but that there is not yet a generally accepted definition. Two aspects that can be found in all definitions are: 1) integration of different disciplinary perspectives and 2) an outcome of the interdisciplinary process which could not have been achieved by a single discipline alone. A variety of so-called 'interdisciplinary' competencies is required in order to collaborate successfully with researchers from other disciplines in finding solutions to complex problems. In this report, a large number of these competencies have been described, which were drawn from articles published in the field of interdisciplinary education. Although a comprehensive list and description of required competencies is still lacking, we have summarized a set of skills and attitudes that were mentioned frequently and can be trained and assessed in assignments. For assessment purposes, there are some well-designed rubrics already available. However, these are mainly focused on writing assignments in which students have to produce an essay, review or research paper on an interdisciplinary topic. Rubrics to assess interdisciplinary competencies other than writing are lacking. To meet the needs for teachers and students alike, we developed an assessment matrix consisting of a set of rubrics which can be used to evaluate a larger variety of interdisciplinary competencies. The matrix can be adapted in each course or curriculum to cover the required learning goals on which individual assignments are focused. An elaborate rubric, focused on writing interdisciplinary papers, is also included. This rubric has been used, evaluated and improved over the past few years in interdisciplinary courses both in the Department of Biology at Utrecht University, as well as in interdisciplinary courses at the University College Utrecht.

Hopefully, the interdisciplinary assessment matrix presented at the end of this report will support the development of interdisciplinary working and thinking abilities and enrich students' disciplinary education to prepare them even better for their future professional environment and the complexity of pressing global issues.

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Appendices

APPENDIX A
Grading rubric from "Targeted assessment rubric: An empirically grounded rubric for interdisciplinary writing".
From: Boix Mansilla et al. (2009)

[Boix Mansilla, V., Dawes Duraisingh, E., Wolfe, C.R., & Haynes, C. (2009). Targeted Assessment Rubric: An Empirically Grounded Rubric for Interdisciplinary Writing. The Journal of Higher Education 80 (3) 334-353.]

Targeted Assessment Rubric for Interdisciplinary Writing

Category 1: Purposefulness

GUIDING QUESTION	NAÏVE	NOVICE	APPRENTICE	MASTER
1.1. Does the student's framing of the problem invite an integrative approach?	The paper does not contain an identifiable purpose or the purpose is unclear.	The paper contains a discernible purpose but it is not clear that this purpose calls for an integrative approach. *Or* The student does identify a problem that calls for an integrative approach but the purpose of the paper is not clearly stated or the purpose is unviable.	The student clearly states a purpose that calls for an integrative approach. However, the student offers no clear rationale or justification for taking this approach. *Or* The purpose for the paper appears somewhat ambitious.	The student clearly states a purpose that calls for an integrative approach and provides a clear rationale or justification for taking this approach.
1.2. Does the student use the writing genre effectively to communicate with his or her intended audience?	There is little sense of an academic genre being used and the intended audience is unclear.	An academic genre is discernible but multiple violations of the genre (e.g. organization, tone, referencing, vocabulary) limit the student's ability to communicate with the intended audience. *Or* The writing is not fluid. It requires multiple readings.	An academic genre is clear and generally adhered to. The student is obviously aware of the intended audience, which often represents more than one discipline. The paper reads fluently No innovation within the genre is visible or if there is any attempt at innovation it is not effective The paper may include minor errors in tone, mechanics and referencing.	An academic genre is clear and consistently adhered to. The student is obviously aware of the intended audience, which often represents more than one discipline. Any innovation within the genre is effective and deliberate

Category 2: Disciplinary Grounding

GUIDING QUESTION	NAÏVE	NOVICE	APPRENTICE	MASTER
2.1. Does the student use disciplinary knowledge accurately and effectively (e.g., concepts, theories, perspectives, findings, examples)?	A disciplinary knowledge base is not discernible in the sense that the ideas and information included do not stem from any particular disciplinary tradition. Misconceptions and folk beliefs abound. In some cases jargon is used with little evidence of understanding. *And/or* the student misuses sources in a major way (e.g., non-credible sources, misunderstanding the meaning of source(s), relying too heavily on one source.	The student uses disciplinary concepts, theories, perspectives, findings, or examples in simplistic, general, or mechanical ways—as in the "textbook" version of a discipline. Key claims are sometimes not supported, or concrete disciplinary examples are disconnected from key claims. Some misconceptions and unwarranted use of jargon may be present. Sources are used pro-forma.	Concepts and theories are used effectively in accordance to their disciplinary origins, in ways adopted by disciplinary experts. Theories and generalizations are consistently supported with examples or findings from the disciplines involved. Conversely, concrete cases and examples are interpreted with disciplinary concepts and theories. Relevant and credible sources are used intelligently to advance the argument of the piece, though the paper may have too many unnecessary sources, or key sources may be missing.	In addition to the qualities outlined at Level 3, a well-organized network of concepts, theories, perspectives, findings, and examples within one or more of the selected disciplines is clearly visible. Some insightful new examples, interpretations, or responses within the selected disciplines may be present. There is sophisticated use of sources. The sources used are relevant and credible and integrated thoughtfully and purposefully to advance the student's argument.
2.2. Does the student use disciplinary methods accurately and effectively (e.g., experimental design, philosophical argumentation, textual analysis)?	The student shows little to no awareness of the methods, habits of mind, and validation criteria by which knowledge is constructed and verified by the disciplines. Opinions and information summaries are presented as matter of facts.	The student shows awareness of or uses disciplinary methods and modes of thinking in one or more of the included disciplines, but employs them mechanically, superficially, or algorithmically. There may be oversimplifications and misconceptions about methods (e.g., if someone assumes statistics results are true).	The student accurately employs methods, modes of thinking (e.g., ways to select evidence or construct causal accounts), and validation criteria to construct knowledge in one or more of the selected disciplines.	The student accurately employs methods, habits of mind, and validation criteria to construct knowledge in one or more of the selected disciplines. He or she does so effectively, exhibiting language that describes the constructed nature of disciplinary knowledge (e.g., the provisional nature of insights, the limits of generalizations, the multiplicity of interpretations).

Category 3: Integration

GUIDING QUESTION	NAÏVE	NOVICE	APPRENTICE	MASTER
3.1. Does the student include selected disciplinary perspectives r insights from two or more disciplinary traditions (presented in the course of from elsewhere) that are relevant to the purpose of the paper?	The paper shows no evidence that disciplinary perspectives are used to address the paper's purpose. Multiple perspectives or points of view may be considered but these do not represent *disciplinary* views and/or are not clearly related to the paper's purpose	The paper includes two or more relevant disciplinary perspectives or fields but the connections between the included disciplinary insights and the purpose of the work are superficial or unclear. Crucial disciplinary perspectives may be missing.	The paper includes two or more relevant disciplines or fields. Selected disciplinary insights are clearly connected to the purpose of the work. Disciplinary perspectives that are tangential to the purpose may be present, or relevant perspectives missed.	The paper includes two or more relevant disciplines or fields. Selected disciplinary insights are clearly connected to the purpose of the work. No unrelated disciplinary insights appear and no crucial perspectives are missing. If the paper includes some tangential perspectives which are, however, original it should be considered Level 4 for this criterion.

3.2. Is there an integrative device or strategy (e.g., a model, metaphor, analogy)?	The student may explore the topic in a holistic way but connections are unclear and there is no obvious sense of integration	The student may explore the topic in a holistic way, making valid connections across disciplinary or field perspectives; however, insights from different perspectives are not integrated coherently or effectively. In some cases, disciplinary concepts, theories, perspectives, findings, or examples are placed side by side; connections and analogies are made but no overall coherent integration is discernible.	An integrative device (e.g., a leading metaphor, a complex causal explanation) clearly brings disciplinary insights together in a generally coherent and effective way.	A novel, imaginative, or well-articulated integrative device (e.g., a leading metaphor, a complex causal explanation) is used to bring disciplinary insights together in a coherent and effective way.
3.3. Is there a sense of balance in the overall composition of the piece with regard to how the student brings disciplinary perspectives or insights together to advance the purpose of the piece?	The paper shows an imbalance in the way particular disciplinary perspectives are presented in light of the purpose of the work (e.g., particular disciplinary perspectives are given disproportionate weight for no obvious reason).	The student attempts to balance perspectives but builds this on artificial or algorithmic grounds rather than substantive ones (e.g., giving equal weight to each disciplinary perspective studied irrespective of its substantive relevance to the problem at hand).	Disciplinary insights in the paper are generally balanced on substantive grounds in light of the purpose of the work. However, one or more aspects of the argument may be weakly addressed.	Disciplinary insights are delicately balanced to maximize the effectiveness of the paper in light of the purpose of the work. The integration is elegant and coherent and there are no distractions in the building of the argument.
3.4. Do the conclusions drawn by the student indicate that understanding has been advanced by the integration of disciplinary views?	The student attempts to make connections across different perspectives but these are unrelated to the apparent purpose of the paper.	Minor efforts at integration are present. Or a language of integration is present but is used mechanistically to yield minimal advancement toward the intended purpose.	The student makes a valid integration of disciplinary insights to generate understandings linked to the purpose of the paper. However, some obvious opportunities to advance the purpose of the paper are overlooked or undeveloped.	The student takes full advantage of the opportunities presented by the integration of disciplinary insights to advance his or her intended purpose both effectively and efficiently. The integration may result in novel or unexpected insights.

Category 4: Critical Awareness

GUIDING QUESTION	NAÏVE	NOVICE	APPRENTICE	MASTER
4.1. Does the student show awareness of the limitations and benefits of the contributing disciplines or how the disciplines intertwine?	There is no awareness of the differing contributing disciplines or fields or their benefits or limitations (e.g., the topic is only approached from a commonsense or very general standpoint.	There is awareness of which disciplines are being used but there is no or only brief discussion of the limitations and/or benefits of the disciplinary contributions. There may be some misconceptions about how the disciplines are being used.	The benefits and/or limitations of the differing contributing disciplines or fields are sufficiently and clearly discussed. Some of the points made may be general or obvious.	The benefits and/or limitations of the differing contributing disciplines or fields are discussed clearly, insightfully, and in relationship to one another (e.g., students not only describe individual contributions but highlight how views complement, balance, add empirical grounding or put into question insights from other disciplines included in the work).
4.2. Does the student exhibit self-reflection?	The student does not consider the strengths and limitations of his or her own paper. Ideas are presented at face value without skepticism or reflection.	Comments on the strengths and limitations of the paper and its integrative approach seem mechanical, superficial, or in passing. Ideas are mostly presented at face value without skepticism or reflection.	There is sufficient comment on the strengths and/or limitations of the paper and its integrative approach, although the points made may be general or obvious.	There is consistent awareness of the strengths and limitations of the paper and its integrative approach. A tentative tone is adopted and alternative integrative approaches may be considered.

APPENDIX B
Grading rubric from "Meeting the challenge of interdisciplinary assessment"
(Olcese et al. 2014)

CATEGORY	**BASIC – F** (... POINTS)	**NOVICE – C** (... POINTS)	**INGENIOUS – B** (... POINTS)	**MASTERY – A** (... POINTS)
1. Problem Framing & Scope Weight __%	1.1. Project/purpose/thesis is not present or extremely unclear to the point where the audience does not understand the problem. 1.2. Disciplines used do not directly apply to issue at hand. 1.3. Ideas and issues are very unclear.	1.1. Project has a purpose/thesis that is missing information or contains too much information. The audience has a general but not clear understanding. 1.2. Discipline use is faulty and contains 3+ extraneous subject use. 1.3. Ideas and issues are unclear.	1.1. Project has a well-stated purpose/ thesis which enables audience to have a good understanding of issue at hand but is missing minor essential elements or contains extraneous information. 1.2. Appropriate disciplines/ subjects used. 1-2 extraneous topics that do not tie into the presentation well. 1.3. Ideas and issues delineated well.	1.1. Project has a clearly stated purpose or thesis which enables the audience to clearly understand the issue at hand. 1.2. Appropriate disciplines/ subjects used. No extraneous topics used. 1.3. Ideas and issues are clearly delineated.
2. Disciplinary Knowledge Weight __%	2.1. Faulty base knowledge. Basic understanding in chosen topics is not present. 2.2. Inappropriate use of knowledge. Severe errors in application of discipline knowledge.	2.1. Baseline subject knowledge in chosen topics. 2.2. Appropriate use of knowledge. Some (severe) errors in application of discipline knowledge to issue at hand.	2.1. Good base subject knowledge and demonstrated basic understanding in chosen topics. 2.2. Appropriate use of knowledge. Slight errors in discipline application to issue at hand.	2.1. Strong base subject knowledge. Demonstrated depth in understanding of chosen topics. 2.2. Appropriate use of knowledge. Correctly utilizes discipline knowledge in application to issue at hand.
3. Integration of Ideas Weight __%	3.1. Provides multi-dimensional solutions that are not feasible and/or practical due to little understanding of the issue at hand. Connections of ideas is faulty. 3.2. Integration is not present or is irrational and/or ineffective. Imbalance of disciplines detracts from intention of the project. 3.3. Unclear or non-present findings, conclusions, recommendations, and/or examples. Or said topics not grounded in disciplinary knowledge. 3.4. Ideas are laundry-listed and are not well explained and/or integrated.	3.1. Provides multi-dimensional, practical conclusions. Ideas may not be completely feasible because of errors or misunderstanding of the issue at hand. Ideas are connected, but not seamlessly. 3.2. Integration is present but is irrational or ineffective. Disciplines are integrated but very imbalanced. 3.3. Decent findings, conclusions, recommendations, and/or examples with connections to disciplinary knowledge. 3.4. Basic range of subjects integration present. Ideas somewhat laundry-listed and do not contain explanations or integration.	3.1. Provides multi-dimensional, feasible, practical conclusions. Ideas are connected, but not seamlessly. 3.2. Integration is present and for the most part effective. Disciplines are integrated but are imbalanced. 3.3. Sound findings, conclusions, recommendations, and/or examples grounded in discipline knowledge. 3.4. Good range of subject integration opportunities are exploited.	3.1. Provides multi-dimensional, feasible, practical conclusions with multi-faceted and seamlessly connected ideas. 3.2. Integration is rationale and effective. Disciplines are both integrated and balanced. 3.3. Quality findings, conclusions, recommendations, and examples from grounded discipline knowledge. 3.4. Full range of subject integration opportunities have been sought out and exploited.

4. Clarity of Purpose Weight __%	4.1. Does not grasp the breadth and depth of the issue in question to an acceptable level. 4.2. A general purpose of investigation is present but not to a satisfactory level.	4.1. Understands the scale of the issue in question but does not effectively communicate it. 4.2. Defines purpose of investigation to a satisfactory level, but contains extraneous matter or loose ends.	4.1. Demonstrates a general understanding of the issue in question's breadth or depth. 4.2. Defined purpose of investigation is present.	4.1. Demonstrates clear understanding of the issue in question's breadth or depth. 4.2. Clearly defines the purpose of investigation.
5. Reflection Weight __%	5.1. Ideas in project are connected and demonstrate minimal reflection on the importance of the issue at large. 5.2. Course Specific Reflection (if desired)	5.1. Connections of ideas demonstrate some reflection on disciplinary interconnectivity and the importance of the issue at large. 5.2. Course Specific Reflection (if desired)	5.1. Connections of ideas indicate that the student has reflected on the interconnectivity and the importance of the issue at large. 5.2. Course Specific Reflection (if desired)	5.1. Clear and delineated connections of ideas indicate that the student has reflected on the interconnectivity and the importance of the issue at large. 5.2. Course Specific Reflection (if desired)
6. Appropriate Presentation Weight __%	6.1. Information is conveyed in such a way that it detracts from the understanding of the problem at hand. 6.2. Presentation order is illogical and/or has discrepancies that detract from the logic, articulation, fluidity, or the presentation of ideas. Appropriate tone and/or depth is not present. 6.3. Terms not defined appropriately or project presented with terminology in such a way that it detracts from the audience's understanding. And/or use of inappropriate terminology or language. 6.4. Errors in grammar, punctuation, spelling and format distract from the project content. Project format is generally incorrect.	6.1. Information is conveyed in such a way that the audience has a general understanding of the problem at hand. Instances of laundry-listing are present and slightly detract from the coherence of the project. 6.2. Presentation order has discrepancies in logic or fluidity. Ideas are not well articulated. Appropriate tone and depth present, but is not overall effective. 6.3. Appropriate terms used but not defined fully for audience/setting context. 6.4. Grammar, punctuation, spelling and format contain significant errors that detract from the project content slightly. Project format is still generally correct.	6.1. Information is conveyed in such a way that the audience understands the scope of the problem and ideas are well conveyed. Minor instances of laundry-listing that do not detract from the coherency of the project. 6.2. Presentation order is logical and fluid with minor discrepancies. Ideas are articulated and conveyed well. Effective tone and depth present. 6.3. Terms appropriately defined and used as needed for audience/setting; minor discrepancies in use or understanding of terminology or language. 6.4. Proper grammar, punctuation, spelling and format used throughout with minimal errors. Project format uses general correctness.	6.1. Information is conveyed in such a way that the audience understands the scope of the problem. Coherently conveyed ideas (no laundry-listed subjects). 6.2. Presentation order is logical and fluid. Ideas are articulated and conveyed effectively. Appropriate and effective tone and depth are present. 6.3. Terms appropriately defined and used as needed for audience/setting; appropriate of terminology and language. 6.4. Proper grammar, punctuation, spelling and format use throughout with no errors.

APPENDIX C
Using concept maps to assess interdisciplinary integration of green engineering knowledge
Borrego et al. (2009).

C1. The steps given to students to help them construct a concept map

1. Write down the major terms or concepts you know about a selected topic (*e.g.* French fries or green engineering design).
2. Write each concept or term on a separate sticky note.
3. Sort through the sticky notes, putting terms you do not understand to one side. Also put aside those that are not related to any other term. The sticky notes left over are the ones we will use to construct the concept map.
4. Arrange the sticky notes so that related terms are close to each other.
5. Stick the notes to a piece of paper as soon as you are satisfied with the arrangement. Leave a little space for the lines we'll draw.
6. Draw lines between the terms you think are related.
7. Write on each line the nature of the relationships between the terms.
8. If you put any card aside in step 3, go back and see if some of them will fit into the concept map you have constructed. If they do, be sure to add the lines and relationships of the new items. Create new sticky notes for new concepts that you think of as you are creating your map.
9. Your assignment today will be to construct a concept map of "green engineering design". Write this term at the top center of your large sheet of paper, then brainstorm related ideas on the sticky notes provided, arrange them, and draw relevant links.

One extra note: like design, concept mapping is a creative activity with many possible "correct" answers.

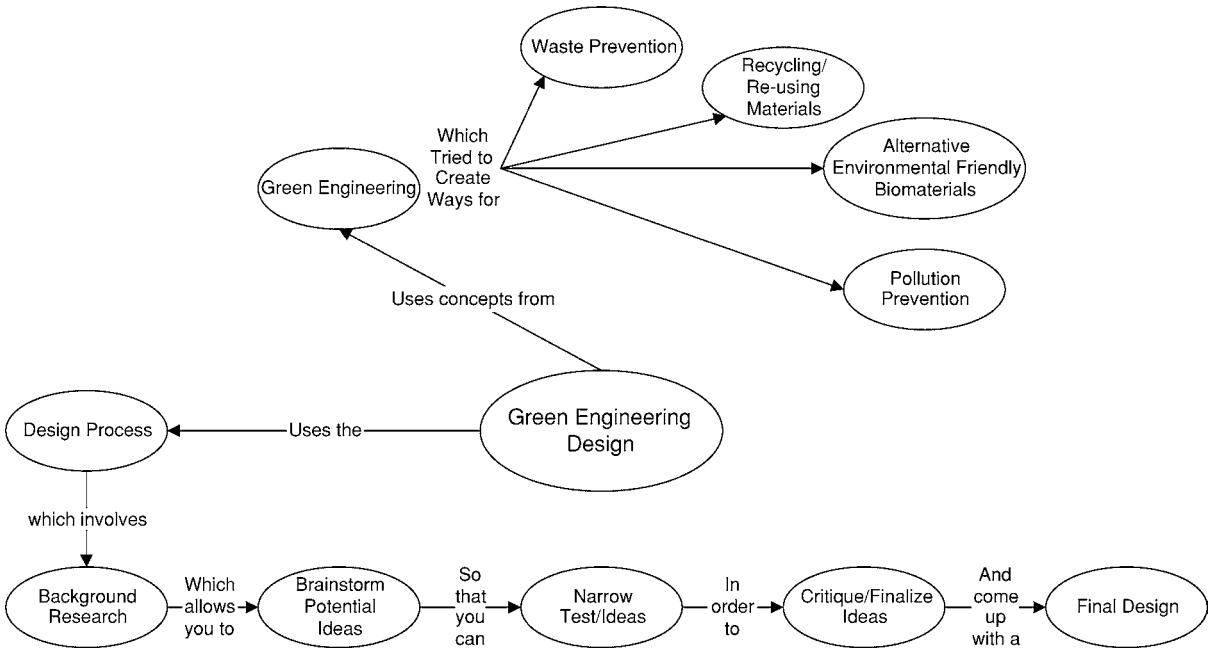

FIGURE C1

Pre-course Concept Map for Student A, with the Largest Gain.
(from: Borrego *et al.* 2009).

C2. Example of the improvement seen at the start (first concept map) and end (second concept map) of the course in the construction of the concept maps.

At the end of the course the student used more appropriate concepts and there was an increased visual complexity.

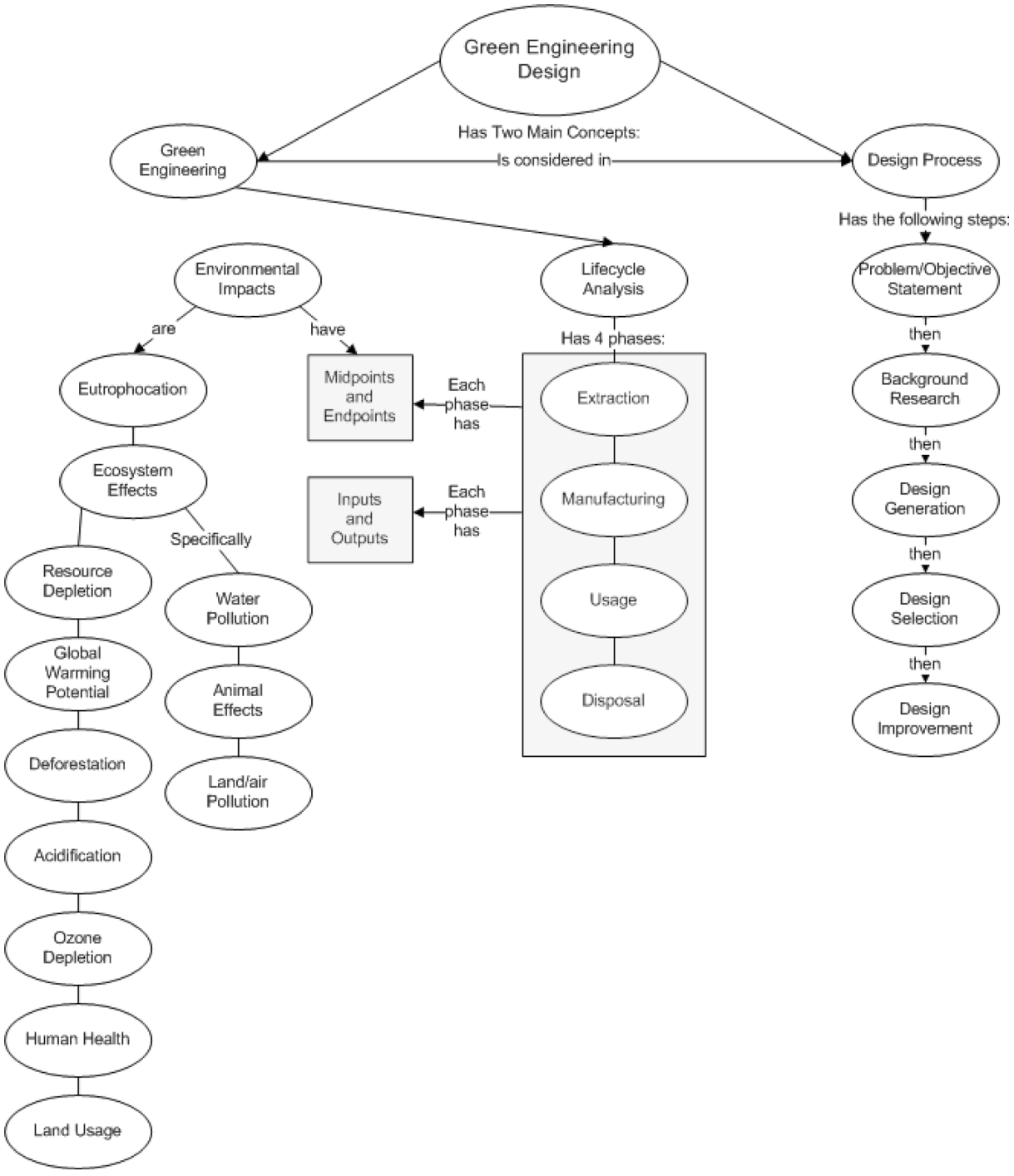

FIGURE C2

Post-course Concept Map for Student A, with the Largest Gain
(from: Borrego *et al.* 2009).

APPENDIX D
The Interdisciplinary Science Rubric (IDSR). Teacher version for grading.
From: Tripp & Shortlidge (2020)

CATEGORY	CRITERIA	NAIVE – (0)	NOVICE (1)	INTERMEDIATE (2)	MASTERY (3)	SCORE
OBJECTIVE	**1.1. Purpose:** What is problem and task? Provide the background information to introduce and frame the problem/ task.	Does *not* include background information	Includes background information that *moderately* reviews the subject matter but *inaccurately* reports material. OR: includes minimal background information, but *accurately* reports any historical and/or current material to frame the problem.	Includes background information that *moderately* reviews the subject matter and *accurately* reports any historical and/or current material to frame the problem.	Includes background information that *sufficiently* reviews the subject matter and *accurately* reports any historical and/or current material to frame the problem.	*/3*
	1.2. Approach: How will you approach the problem/ task? Formulate a plan that clearly outlines your approach (steps/procedures).	Does *not* include a plan	Includes a plan that *unclearly* and/or *insufficiently* addresses the problem/ task at hand.	Includes a plan that *moderately* outlines steps/ procedures that will be accomplished but *excludes* steps/ procedures that are discussed further in the essay.	Includes a plan that *clearly* outlines steps/ procedures that will be accomplished to address the problem/task at hand.	/3
	1.3. Credibility: What sources will you include? Use peer-reviewed articles and/or other supporting information that are relevant to the problem.	Does *not* include peer-reviewed articles and/or information	Includes peer-reviewed articles and/ or information, but they are *irrelevant* to the problem	Includes peer-reviewed articles and/ or information that are *tangential* to the problem	Includes peer-reviewed articles and/ or information that are *relevant* to the problem	/3
					Average *Objective* Score	/3
DISCIPLINARY GROUNDING	**2.1. Disciplines/ Experts:** What disciplines and/or experts will be involved? Include two or more disciplines and/or experts in your approach to the problem/task.	Does *not* include disciplines and/or experts	Includes only *one* discipline and/or expert relevant to student's approach	Includes *two or more* disciplines and/ or experts but some are *irrelevant* to student's approach	Includes *two or more* disciplines and/or experts *relevant* to student's approach	/3
	2.2. Disciplinary reasoning: Why are you including *each* discipline and/ or expert? *Meaningfully* explain the reasoning behind the use of each discipline and/or expert.	Does *not* include reasoning behind using disciplines and/or experts.	Includes *inaccurate* or *oversimplified* reasoning for all contributing disciplines and/or experts	Includes *accurate, informed* reasoning behind one or multiple but *not all* contributing disciplines and/or experts	Includes *accurate, informed* reasoning behind all contributing disciplines and/or experts	/3
	2.3. Methods & Tools: What methods will each discipline and/or expert use? Include techniques/procedures/tools from contributing disciplines and/or experts.	Does *not* include methods (techniques/ procedures/ tools)	Includes *inaccurate* methods (techniques/ procedures/tools) for all contributing disciplines and/or experts	Includes *accurate* methods (techniques/procedures/tools) from one or multiple, but *not all* contributing disciplines and/or experts	Includes *accurate* methods (techniques/procedures/tools) from all contributing disciplines and experts	/3
					Average *Disciplinary Grounding* Score	/3

INTEGRATION	**3.1. Leveraging Disciplines/ Experts:** How will each contributing discipline and/or expert build off one another to effectively address the problem/task in a way that one contributor cannot? Specifically address how each discipline's and/or expert's contribution (knowledge/methods) will be useful for the other disciplines and/or experts?	Does *not* include ways to leverage the disciplines and/or experts	Lists disciplines/experts knowledge/ methods contribution *without* building off the knowledge/ methods from each contributor	Leverages contributing disciplines and/or experts by building off knowledge/ methods to effectively address the problem/task in a way that one contributor cannot but *does not* consider all disciplines involved	Leverages contributing disciplines and/or experts by building off knowledge/ methods to effectively address the problem/task in a way that one contributor cannot	/3
	3.2. Collaboration: How will you foster successful partnerships? Include and *explain* two or more ways to build community and respect among different disciplinary team members (e.g., establishing common ground and language, overcoming different perspectives, etc.).	Does *not* include *nor* explain ways to build community and respect among different disciplinary team members.	Lists *two or more* logical ways but *does not* explain how to build community and respect among different disciplinary team members	Includes and *sufficiently* explains *one* logical way to build community and respect among different disciplinary team members	Includes and *sufficiently* explains *two or more* logical way to build community and respect among different disciplinary team members	/3
					Average *Integration* Score	/3
BROADER AWARENESS	**4.1. Societal Impact:** How does your proposed solution impact society? Include why your solution is locally and more broadly relevant to society and what/who will be affected? (e.g., economic, politics, social, health, etc.).	Does *not* include local or broader societal impacts *nor* what/who will be affected.	Includes *only* local or broader (not both) societal impacts and does not sufficiently explain what/who will be affected	Includes local and broader (not both) societal impacts and *moderately* explains what/who will be affected OR: Sufficiently explains what/who will be affected but includes *only* local or broader (not both) societal impacts	Includes local and broader societal impacts and *sufficiently* explains what/who will be affected	/3
	4.2. Limitations: What are the potential limitations to your plan and how will you overcome these barriers? Forecast possible limitations of your plan and provide resolutions.	Does *not* include limitations *nor* resolutions.	Includes potential limitations but *does not* explain resolutions to overcome these barriers	Includes potential limitations of plan and *moderately* explains resolutions to overcome these barriers	Includes potential limitations of plan and *sufficiently* explains resolutions to overcome these barriers	/3
					Average *Broader Awareness* Score	/3
FORMAT	Format, Grammar, Structure: Have you followed all formatting guidelines? Does your proposal have an introduction, body & conclusion?					/3
					TOTAL SCORE	/15

APPENDIX E
Matrix with assessment rubrics of interdisciplinary learning goals & competencies.
UU-2020

Below, we describe a general rubric for interdisciplinary education. This rubric is the result of the integration of several rubrics which have been used in some programs at Utrecht University. The rubric includes seven categories which we consider as the most important for interdisciplinary learning: (1) Disciplinary grounding, (2) Perspective taking , (3) Common ground & Integration (4) Critical Reflection (5) Collaboration, (6) Communication, (7) Adaptability and creativity. The first three are typical learning goals in interdisciplinary learning, while the last four are competencies or general academic skills that are however vital for interdisciplinary work.

The rubric can be used to assess interdisciplinary competencies regardless the 'product' of the learning activity. Which of the seven categories are used for assessing an assignment or learning activity, depend on the main learning objectives of the assignment. The weight of the used categories does also depend on the learning objectives of the specific assignment used in a course.

First we describe the seven general interdisciplinary categories (Table 1), next these are transformed into a rubric (Table 2), and lastly we provide two example rubrics for specific assignments: an oral assignment ('the fictitious dialogue') and a writing assignment for an interdisciplinary paper.

TABLE 1: Seven interdisciplinary categories

CATEGORIES	DESCRIPTION	ASSESSMENT CRITERIA
1 Disciplinary grounding	Disciplinary grounding involves having a basic knowledge and understanding of the involved disciplines as well as ways in which their knowledge is constructed, validated and communicated. This implies knowing which phenomena are being studied in the disciplines (basic disciplinary concepts, theories, assumptions), understanding the basic assumptions of these disciplines, the epistemology, its methods and ways of validation, and genres of communication (e.g. a research paper, a review, a law, a historical narrative).	▪ Justification of the need for an interdisciplinary approach. ▪ Justification of the choice of contributing disciplines: which disciplines are relevant regarding the problem, which are chosen to be used, and which are left out, and why? ▪ Critical overview of the 'state of art' of the relevant disciplines regarding the problem. ▪ Insights are presented in a coherent way and relevant terms are explained.
2 Perspective taking	Perspective taking involves analyzing the problem from the position of each interested discipline and identifying their commonalities and differences. It also encompasses an attitude of disciplinary humility and open mindedness to- and valuing of different perspectives, and the willingness to reflect on of one's own biases and assumptions	▪ Open mindedness: appreciation of and genuine interest in different (personal and disciplinary) perspectives; ▪ Disciplinary humility: awareness of his/her own biases and assumptions and of the limitations of his/her own discipline. ▪ Valuing of other (non-) disciplinary perspectives as a part in the problem-solving process.

3 Common ground & Integration	**Common ground** is the shared basis between conflicting disciplinary insights or theories. This is a creative process that involves modifying or reinterpreting disciplinary elements that conflict. It also incorporates the identification of how terms are used differently in different disciplines and defining problems explicitly in neutral terms. **Integrating perspectives** involves generating a new understanding that would not have been possible using a single discipline. It includes being able to use integration techniques (e.g. models, metaphors) to find new holistic understanding	▪ Clear and critical analysis of (methodological and theoretical) strengths and weaknesses of each disciplinary insight; ▪ Clear analysis of similarities and differences between disciplinary insights related to the research question(s). ▪ Common ground has been found. ▪ Key concepts are defined in neutral terms. ▪ Disciplinary insights are integrated into a new understanding of the problem to answer the research question.
4 Critical reflection	Reflection is a purposeful activity in which experiences are analyzed, in order to learn and improve. Evaluating an interdisciplinary project and its value and difficulties makes students aware of the intricacies of interdisciplinary work, and considering how to do it better next time helps consolidate the learning experience. A broader awareness is reflected in how the proposed solution may impact society (who/what will be affected in terms of e.g. health, politics, economics, social structures, etc.). In addition, the potential limitations of the proposed solution are addressed.	▪ The reflection provides valuable insight in the phases process, the challenges faced, and the learning gain. ▪ The reflection shows implications for future learning. ▪ The reflection addresses a broader awareness by explaining the impact of the proposed solution and by addressing its potential limitations (and possibly strategies to overcome these limitations).
5 Collaboration	Interdisciplinary collaboration requires more of students' collaboration skills than disciplinary teamwork does. First, the need to explain and discuss perspectives to each other clearly and build on each other's ideas is more challenging in interdisciplinary teamwork for students than when collaborating with peers from the same discipline, where they speak the same language and do not need to explain and discuss everything extensively. Due to the lack of experience students have in each other's disciplines where it is not always possible to critically examine the works of others, they also need to learn to trust and respect one another. Team and task regulation is needed in all teamwork, although in interdisciplinary collaboration this more effort from students because they need each other's contributions and feedback in all parts of the project and are not able to divide tasks as they normally do. Further, the complexity of interdisciplinary projects requires compromising in order to keep the project manageable.	▪ Listening with an open mind to other personal and/or disciplinary perspectives; ▪ Explaining in layman's words of one's own disciplinary perspective; ▪ Trusting and respecting the expertise of teammembers; ▪ Providing constructive feedback and shows openness to feedback from others; ▪ Clearly exchanging goals, priorities and values, and making concessions to formulate a common goal; ▪ Awareness of and sensitivity towards the position of other team members and see how disagreements can occur before they did.
6 Communication	Communication in interdisciplinary teamwork includes being open minded and non-judgmental in listening to and trying to understand other's perspectives. Explaining clearly is important as peers from other disciplines do not share the same background as is the awareness of the diversity of disciplinary language, differences in understandings of concepts and terms	▪ Is aware of the level of knowledge of the audience he/she is addressing Can patiently explain disciplinary knowledge to others without using disciplinary jargon. ▪ Listens to others, is open minded and non-judgmental. ▪ Is able to effectively communicate his/her findings regardless of the medium used (writing, oral presentation, etc.)
7 Adaptability and creativity	Interdisciplinary work is creative and innovative, with unknown outcomes and a risk of failure. Thus, in disciplinary education, students have to cope with the fact that teachers do not have all the answers. This requires a tolerance for ambiguity, the courage to venture in unfamiliar space, to grapple with periods of insecurity, and to make mistakes.	▪ Thinks creatively in situations that are unfamiliar and doesn't give up easily. ▪ Thinks out of the box and takes risks because he/she realizes risk aversion stands in the way of originality. ▪ Sees challenges as an opportunity to develop and, if mistakes are made, sees them as a learning opportunity. ▪ Is aware that interdisciplinarity problems often do not have a right or wrong answer and that more solutions are possible.

TABLE 2 Rubric interdisciplinary competencies

CATEGORIES	INSUFFICIENT (NOVICE)	SUFFICIENT-GOOD (INTERMEDIATE)	GOOD-EXCELLENT (MASTERY)
Disciplinary grounding	▪ The complexity of the problem is not well indicated and the need for an interdisciplinary approach is not justified. ▪ Key disciplinary insights are described too superficially, and/or some key concepts missing. ▪ The selection of one or more disciplines is questionable and/or important disciplines related to the problem are lacking. ▪ Insights are not presented in a coherent and balanced way, and definitions on key concepts are missing.	▪ The problem is well introduced, but the relevance could be more elaborate. ▪ It is explained why the involved disciplines are required, and why others are left out. ▪ Nice elaboration on some of the disciplinary insights but not all insights could be approached more in depth. ▪ The presentation of the insights could be more coherent and balanced, not all relevant terms are clearly explained.	▪ The problem is challenging, well anchored in literature review, and its societal relevance is made clear. ▪ Shows thorough understanding of the (disciplinary) insights, assumptions, and context. ▪ Relevant terms and concepts are explained clearly. ▪ A clear justification is given why the complexity of the problem exceeds the boundaries between disciplines. ▪ The most relevant disciplines that relate to the problem are covered and well justified, as well as the ones left out.
Perspective taking	▪ Shows no real open mindedness towards other ideas and beliefs. ▪ Does not question his/her own (disciplinary) biases and assumptions. ▪ Has difficulties including other viewpoints as part of the problem solving process.	▪ Shows interest in other viewpoints although superficially. ▪ Is reluctant to temporarily set aside his/her own viewpoints and beliefs. ▪ Values other (non-) disciplinary perspectives as a valuable addition, rather not quite as equally important.	▪ Open mindedness: appreciation of and genuine interest in different (personal and disciplinary) perspectives; ▪ Awareness on of his /her own biases and assumptions and of the limitations of his/her own discipline. ▪ Values other (non-) disciplinary perspectives as a part in the problem-solving process.
Common ground & Integration	▪ Strengths and weaknesses of each disciplinary insight are quite superficial and based on preferences rather than critical analysis. ▪ Similarities and differences of disciplinary insights are there, but analysis and structure are lacking. ▪ Key concepts are not clearly defined. ▪ As a result the disciplinary insights are presented next to each other rather than in a connected and integrated way.	▪ Clear analysis of strengths & weaknesses of most disciplinary insights, but not all aspects are elaborated on. ▪ The differences and similarities are analyzed, though somewhat superficially. ▪ Some key concepts are defined. ▪ An endeavor to find common ground is shown by trying to reconcile or connect disciplinary insights.	▪ Clear and critical analysis of strengths and weaknesses of each disciplinary insight, with respect to theories, methods and assumptions. ▪ Clear analysis of similarities and differences between disciplinary insights related to the research question(s). ▪ Key concepts are defined in neutral terms. ▪ Common ground has been found and is clearly explained. ▪ Integration of the disciplinary insights resulted in a new or reconciled understanding. The new insights are applied to the problem or case, providing new directions for solutions or answers.
Critical reflection & Broader awareness	▪ The reflection does not move beyond a description of the learning experience. ▪ The reflection hardly describes societal impacts nor explains what/who will be affected by the proposed solution. ▪ Potential limitations of the proposed solution are not or hardly addressed.	▪ The reflection provides some insights in the process of integration and learning gain, but the value of the learning to the student is vague and/or unclear. ▪ The reflection includes an indication of some societal impacts and moderately explains what/who will be affected by the proposed solution. ▪ Potential limitations of the proposed solution are addressed as well as some strategies to overcome them.	▪ The reflection provides valuable insight in the phases process, the challenges faced, and the learning gain. ▪ The reflection shows implications for future learning. ▪ The reflection clearly addresses societal impacts of the proposed solution and explains what/who will be affected. ▪ Potential limitations of the proposed solution are clearly described as well as solutions to overcome them.

Collaboration	▪ Is often too submissive or dominant in the collaboration process. ▪ Has difficulty in explaining his/her insights to peers. ▪ Respects and trusts the expertise of some of the team-members; ▪ Is willing to providing feedback but is not very open to feedback from others; ▪ Participates in exchanging priorities but does not take initiative. Has difficulties with compromising. ▪ Can be rude to peers.	▪ Listens to others but does not acknowledge whether he/she understands the other. ▪ Tries to explain his/her insights but shows some difficulty in doing so. ▪ Respects and trusts the expertise of most of the team-members; ▪ Is willing to providing feedback and is mostly open to feedback from others; ▪ Participates in exchanging priorities but does not take initiative. Is willing to compromise. ▪ Is aware of and sensitive towards the position of other team members.	▪ Listens with an open mind to other's personal and/or disciplinary perspectives. ▪ Explains in layman's words of one's own disciplinary perspective; ▪ Trusts and respects the expertise of team-members; ▪ Provides constructive feedback and shows openness to feedback from others; ▪ Clearly exchanges goals, priorities and values, and does concessions to formulate a common goal; ▪ Aware of and sensitive towards the position of other team members and sees how disagreements can occur.
Communication	▪ Has a hard time explaining disciplinary knowledge to a layman's audience, finds it difficult to avoid jargon. ▪ Listens to others, but rather judgmental. ▪ Is not always clear in communicating his/her findings.	▪ Is aware of the level of knowledge of the audience he/she is addressing, but finds it difficult to avoid jargon. ▪ Listens to others, is open minded and non-judgmental. ▪ Is not always clear in communicating his/her findings.	▪ Is aware of the level of knowledge of the audience he/she is addressing Can patiently explain disciplinary knowledge to others without using disciplinary jargon. ▪ Listens to others, is open minded and non-judgmental. ▪ Is able to effectively communicate his/her findings regardless of the medium used (writing, oral presentation, etc.)
Adaptability and creativity	▪ Isn't able to apply learned knowledge to new and unfamiliar situations or outside the familiar disciplinary setting. ▪ Stays within his/her comfort zone not daring to try something new or unfamiliar or gives up easily in trying new situations. ▪ Has a hard time in complex and unstructured situations. ▪ Discards ideas too soon or focusses on one idea from the start without thinking of other possibilities.	▪ Tries to apply disciplinary knowledge in new and unfamiliar settings but gives up too easily or resort to familiar ground if he/she doesn't reach a preferred result. ▪ Starts to venture outside one's comfort zone and explores new and/or creative ways to solve a problem. ▪ Takes risk but falls back on known patterns and working methods if things get hard. This limits the student's creative opportunities. ▪ Can come up with multiple ideas but finds it hard to determine which ideas will be useful in the end.	▪ Thinks creatively in situations that are unfamiliar and doesn't give up easily. ▪ Thinks out of the box and takes risks because he/she realizes risk aversion stands in the way of originality. ▪ Sees challenges as an opportunity to develop and, if mistakes are made, sees them as a learning opportunity. ▪ Is aware that interdisciplinarity problems often do not have a right or wrong answer.

Two examples

Depending on the specific student assignment, one or more categories addressing interdisciplinary learning goals or competencies could be chosen from the rubric, and added to the 'regular' criteria for that assignment. Below, we provide two examples of specific assignments in which interdisciplinary and regular academic skills are combined: one for an oral assignment (the fictitious dialogue), and one for a paper assignment.

EXAMPLE 1:
Oral assignment

Assignment:
The fictitious dialogue[1]

In this assignment, student teams of 4 are asked to write and perform a dialogue about an issue relevant to the course. For the dialogue, two 'thinkers' are chosen, for example Plato, Marx, Mill, Darwin, and students are asked to imagine that they are this person and invent a dialogue between the two. In groups of 4, two students prepare one side of the dialogue, and the other two the other person. The four of them put the dialogue together, and two students perform it in class. The personalized arrangement and speaking in the 'I'-form intensify the experience.

Learning objectives: This learning activity is designed to stimulate perspective-taking and to take an effort to truly engage with different perspectives.

How to use the rubric for this assignment
Since the learning outcomes of this group assignment focus on perspective taking, the interdisciplinary assessment criteria could be in this case dome of the criteria belonging to disciplinary grounding and perspective taking. Collaboration can be added to the criteria because students have to work together to prepare the dialogue and communication could also be added because students have to speak up during the debate.

The Rubric of this assignment can be found on the next page.

EXAMPLE 2:
Writing assignment

In most paper assignments, the first four interdisciplinary categories are used, completed with some regular writing criteria (such as defining an objective, formulating a conclusion and aspects such as structure & writing style). In this example, reflection is added since reflection assignments help students explicate the learning gain (and encourage them to reflect on the (societal) impact of the proposed solution). In addition, these reflections help teachers to learn where students faced difficulties.

The Rubric of this assignment can be found on page 89 & 90

1 This assignment is designed by Dr. Chiara Robbiano (UCU, Utrecht University).

Rubric Fictitious Dialogue (Example 1)

CATEGORIES	INSUFFICIENT (NOVICE)	SUFFICIENT-GOOD (INTERMEDIATE)	GOOD-EXCELLENT (MASTERY)
Disciplinary grounding	▪ Key disciplinary insights are described too superficially, and/or some key concepts missing. ▪ Insights are not presented in a coherent and balanced way, and definitions on key concepts are missing.	▪ Nice elaboration on some of the disciplinary insights but not all insights could be approached more in depth. ▪ The presentation of the insights could be more coherent and balanced, not all relevant terms are clearly explained.	▪ Shows thorough understanding of the (disciplinary) insights, assumptions, and context. ▪ Relevant terms and concepts are explained clearly.
Perspective taking	▪ Shows no real open mindedness towards other ideas and beliefs. ▪ Does not question his/her own (disciplinary) biases and assumptions. ▪ Has difficulties including other viewpoints as part of the problem solving process.	▪ Shows interest in other viewpoints although superficially. ▪ Is reluctant to temporarily set aside his/her own viewpoints and beliefs. ▪ Values other (non-) disciplinary perspectives as a valuable addition, rather not quite as equally important.	▪ Open mindedness: appreciation of and genuine interest in different (personal and disciplinary) perspectives; ▪ Awareness on of his /her own biases and assumptions and of the limitations of his/her own discipline. ▪ Values other (non-) disciplinary perspectives as a part in the problem-solving process.
Collaboration	▪ Is often too submissive or dominant in the collaboration process. ▪ Has difficulty in explaining his/her insights to peers.. ▪ Respects and trusts the expertise of some of the team-members; ▪ Is willing to providing feedback but is not very open to feedback from others; ▪ Participates in exchanging priorities but does not take initiative. Has difficulties with compromising. ▪ Can be rude to peers.	▪ Listens to others but does not acknowledge whether he/she understands the other. ▪ Tries to explain his/her insights but shows some difficulty in doing so. ▪ Respects and trusts the expertise of most of the team-members; ▪ Is willing to providing feedback and is mostly open to feedback from others; ▪ Participates in exchanging priorities but does not take initiative. Is willing to compromise. ▪ Is aware of and sensitive towards the position of other team members.	▪ Listens with an open mind to other's personal and/or disciplinary perspectives. ▪ Explains in layman's words of one's own disciplinary perspective; ▪ Trusts and respects the expertise of team-members; ▪ Provides constructive feedback and shows openness to feedback from others; ▪ Clearly exchanges goals, priorities and values, and does concessions to formulate a common goal; ▪ Aware of and sensitive towards the position of other team members and sees how disagreements can occur.

Rubric Writing Assignment (Example 2)

RUBRIC INTERDISCIPLINARY PAPER			
CATEGORIES	INSUFFICIENT (F/D) (NOVICE)	SUFFICIENT/GOOD (C/B) (INTERMEDIATE)	VERY GOOD/EXCELLENT (A) (MASTERY)
Objective: Problem statement & Justification of interdisciplinary approach	▪ The problem and its relevance are not explained very clearly. ▪ The research question is too broad, or too narrow for an interdisciplinary approach. ▪ The complexity of the problem is not well indicated and the need for an interdisciplinary approach is not justified. ▪ The selection of one or more disciplines is questionable and/or important disciplines related to the problem are lacking.	▪ The problem is well introduced, but the relevance could be more elaborate. ▪ The research question could be more focused and remains a bit broad and imprecise. ▪ The complexity of the problem is indicated, and an interdisciplinary approach is justified. ▪ It is explained why the involved disciplines are required, and why others are left out.	▪ The problem is challenging, well anchored in literature review, and its societal relevance is made clear. ▪ The research question is clearly stated and is researchable (specific and narrowed down). ▪ A clear justification is given why the complexity of the problem exceeds the boundaries between disciplines. ▪ The most relevant disciplines that relate to the research question are covered and well justified, as well as the ones left out.
Disciplinary grounding	▪ Key disciplinary insights are described too superficially, and/or some key concepts missing. ▪ Insights are not presented in a coherent and balanced way, and definitions on key concepts are missing. ▪ Over-reliance on one or two sources and/or sources are not (fully) relevant.	▪ Nice elaboration on some of the disciplinary insights but not all insights could be approached more in depth. ▪ The presentation of the insights could be more coherent and balanced, not all relevant terms are clearly explained. ▪ There is some variety in sources, but not all are relevant or up-to-date.	▪ State of the art of the various disciplinary insights is presented. ▪ Insights of each discipline are coherently presented and relevant terms are clearly explained. ▪ A variety of relevant sources is used, including recent and primary sources.
Common ground & Integration	▪ Strengths and weaknesses of each disciplinary insight are lacking or quite superficial and based on preferences rather than critical analysis. ▪ Similarities and differences of disciplinary insights are there, but analysis and structure are lacking. ▪ An attempt to find common ground and connecting insights is lacking or, when it is made, it is not very structured.	▪ Clear analysis of strengths & weaknesses of most disciplinary insights, but not all aspects are elaborated on. ▪ The differences and similarities are analyzed, though somewhat superficially. The presentation of the analysis could have been better structured/visualized and/or supported by more relevant examples. ▪ An endeavor to find common ground is shown by trying to reconcile or connect disciplinary insights. An attempt to integrate different perspectives is clarified.	▪ Strengths & weaknesses as well as similarities and differences are critically analyzed, with respect to theories, methods and assumptions. ▪ Analysis is presented in a clear way (preferably) by using tables or other visualization. ▪ Common ground is found using (or extending) one of Repko & Szostak's methods, and integration of the disciplinary insights resulted in a new or reconciled understanding. The new insights are applied to the problem or case, providing new directions for solutions or answers.
Conclusion	▪ The main question remains mainly unanswered, or the conclusions are not based on the results that are presented.	▪ Conclusions are given. Part of the research question(s) remain unanswered and/or part of the conclusion is not fully based on the results that are described. Discusses impact of researched material on problem.	▪ The conclusions are clearly described and provide answers to the research question(s). Insightful discussion of impact of the researched material on problem. Further research steps are indicated

Structure and writing style	▪ Structure needs improvement (use of headings, chapters and sections could be more consistent; ordering of information is not always logical. The title is unimaginative. ▪ Writing style is insufficient (e.g. parts are plagiarized; message remains unclear, student's own voice is lacking). ▪ Sources are not correctly cited, and/or reference list is missing or incomplete. ▪ The use of jargon makes the paper unsuitable for a multidisciplinary audience.	▪ Structure could be more optimal (more consistency in use of headings; some parts are ordered in an illogical way; better balance between the various parts). The title is attractive and clarifies the interdisciplinary topic/approach. ▪ Some parts are written in clear language, but other parts remain a bit vague. The student' own voice is recognizable in some or most parts. ▪ Citations are mostly consistently used, and reference list is nearly complete. ▪ The use of jargon in some parts makes the paper less easy readable for a multidisciplinary audience.	▪ The paper is well structured, in a logical order, well-reasoned, and headings and sub-headings are effective. The title is effective and draws the attention of a broad audience. ▪ The paper is written in colorful language, clear and understandable, and in the student's own words. ▪ Correct use of citations, and all information is well documented in the reference list. ▪ The paper reads easily, lacks jargon, attracts the attention and is understandable for a multidisciplinary audience.
Reflection	▪ The reflection on the added value of the interdisciplinary approach is lacking or does not move beyond a description of the learning experience. ▪ A broader awareness is missing: the societal impacts and/or potential limitations of the proposed solutions are not or hardly discussed.	▪ The reflection provides some insights in the process of integration and learning gain. The added value of the interdisciplinary approach is described (but perhaps a bit vague or unclear). ▪ The reflection discusses the societal impacts and/or potential limitations of the proposed solutions.	▪ The reflection provides valuable insight in the learning process, the challenges faced, and the learning gain of the interdisciplinary approach. ▪ The reflection shows implications for future learning. ▪ The reflection shows a broader awareness by addressing the societal impacts of the proposed solution, and discussing potential limitations as well as solutions to overcome them.

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