Review of the Research Literature on Interdisciplinary Education

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Abstract

In response to the increasing demand for interdisciplinary competence, there is a corresponding need to educate students in this area. This report provides an overview of existing research and studies on interdisciplinary education, including reflections and Scholarship of Teaching and Learning. We present various approaches to and reflections on interdisciplinary education, as well as frameworks for assessing and evaluating students and activities in an interdisciplinary context. Throughout the report, we acknowledge the differences between many of the definitions of interdisciplinarity and related concepts applied in the literature, and the impact this has on the discussion. We apply Bloom's taxonomy (1956) and the revised taxonomy by Anderson & Krathwohl (2001) to interpret and contextualize definitions of interdisciplinarity and related terms.

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Introduction

In an increasingly complex and globalized world, there is a call for competence that transgresses traditional disciplinary boundaries. Developing such competence requires education grounded in research. A considerable amount of research has been done on the topic of interdisciplinary education, but the novelty of the field, the lack of standardized definitions, and the varied research approaches can make it a difficult field to navigate. For these reasons, we have conducted a systematic review of the literature on interdisciplinary education, contextualized, assessed, and compared using Bloom's taxonomy (1956) and the revised taxonomy by Anderson & Khratwohl (2001).

The report defines interdisciplinary competence and related concepts, presents theoretical and philosophical literature on interdisciplinarity, and discusses its utility in education. The main body of the report is structured around distinctions we made throughout the research. Perhaps the most central distinction is that between approaches to *measuring, assessing* and/or *evaluating* interdisciplinarity on the one hand and approaches to the *execution* of interdisciplinarity on the other. Within methods for measuring interdisciplinarity, we further distinguish between methods for measuring interdisciplinarity in *programs/activities* and methods for measuring or assessing interdisciplinarity in *students.* The discussion of execution is structured thematically.

Definitions of Interdisciplinarity

A reoccurring term in our report is *interdisciplinary competence*. Competence here encompasses having *knowledge* and/or abilities in the *cognitive processes* dimension, as defined by Anderson & Krathwohl (2001) in their revised version of Bloom's taxonomy. The knowledge dimension of their taxonomy refers to the *what* of learning – what do students know? The cognitive process dimension refers to the *how* – how do students think? Anderson et al. identify four subcategories within the knowledge dimension: factual, conceptual, procedural, and metacognitive knowledge. The cognitive processes dimension has six subcategories: *remember, understand, apply, analyse, evaluate, and create.*

By *interdisciplinary* competence, we refer to those aspects of the knowledge and cognitive process dimension which are typically attributed to interdisciplinarity. For instance, the factual knowledge sub-category will in interdisciplinary settings refer to factual knowledge on topics that are interdisciplinary in nature, such as climate change or artificial intelligence, and/or factual knowledge within fields other than one's own. The procedural knowledge sub-category might include knowledge of the methodologies of other disciplines,

as well as how to approach research in an interdisciplinary setting. Within the cognitive dimension, the analyse sub-category will include the ability to differentiate between, prioritize and organize information from multiple disciplines related to one issue or project, whereas the create sub-category includes the ability to generate hypotheses based on interdisciplinary information and to create products that address interdisciplinary issues. Interdisciplinary competence is thus used as a blanket term covering types of knowledge and cognitive abilities typically attributed to interdisciplinary education.

The original Bloom's taxonomy categorizes learning into three domains: the *cognitive*, *affective*, and *psychomotor* domain. The revised version of Anderson & Krathwohl focuses on the cognitive domain, arguing that affect cannot be isolated from cognition as "... nearly every cognitive objective has an affective component" (Anderson & Krathwohl, 2001, p. 258). In our review, however, we choose to recognize *affect* as a separate dimension, since some of the literature focuses almost exclusively on this aspect of learning. The affective dimension in our report is defined broadly as regarding emotional responses, attitudes, and dispositions, which could be related to disciplines, educational material, real-world issues, other students, stakeholders, etc.

The literature on interdisciplinarity makes use of varying definitions of interdisciplinarity, interdisciplinary understanding, interdisciplinary thinking, etc. Downey et al. (2006), for instance, defined interdisciplinarity as the ability to "work effectively with people who define problems differently" (Downey et al., 2006, p. 107., as cited in Buchmüller et al., 2021). Similarly, Gao et al. (2020) defined interdisciplinarity as integrating "parts of two or more disciplines, focusing on establishing explicit connections between relevant disciplines", building on previous definitions by Klein (2004) and Miller (1982). Defining interdisciplinarity in the context of education, Zhang & Shen (2015) defined interdisciplinary education as "learners building connections between different disciplines, such as integrating knowledge and skills from two or more disciplines in order to solve complex problems or explain sophisticated phenomena.". Especially prominent in the literature is the definition by Boix Mansilla et al. (2000) of interdisciplinary understanding as "the capacity to integrate knowledge and modes of thinking in two or more disciplines or established areas of expertise to produce a cognitive advancement such as explaining a phenomenon, solving a problem, or creating a product in ways that would have been impossible or unlikely through single disciplinary means".

These divergencies of definitions is a source of difficulty when it comes to comparing and synthesizing the research in the field. Since we are conducting a review of a vast array of

literature with varying definitions, we adopt our more general definition of interdisciplinary competence as a baseline and specify where articles have defined interdisciplinary understanding/thinking/competence more narrowly. We see other definitions as falling under our framework, and we can therefore use the taxonomy to deconstruct and understand other definitions. The definition by Boix Mansilla et al. (2000) can for instance be seen as the *organization* (especially *integration*, which is part of the organization sub-category of the cognitive domain) of *knowledge* (some or all the sub-categories of knowledge domain) from different disciplines, to *create* a cognitive advancement in ways that would have been impossible through single disciplinary means. We further make use of the taxonomy to point out the implicit conceptions of interdisciplinarity and related concepts in studies where these are not explicitly defined.

Theoretical and Philosophical Approaches to Interdisciplinary Education

Several articles propose theoretical approaches to interdisciplinary education and place interdisciplinary competence within theoretical or philosophical frameworks. As these articles do not focus primarily on research of education, and therefore technically fall outside the scope of this report, we will not be going in-depth into this area of literature. However, as some of them propose a theoretical groundwork for discussing interdisciplinary competence, we choose to include this section as well.

In *Towards a Philosophy of Interdisciplinarity,* Schmidt (2007) identifies four different domains of interdisciplinarity: an ontological dimension (object-oriented), epistemological dimension (theory-oriented), methodological dimension (methods-oriented), and a problem-oriented dimension. The article further explores how different views on the importance of each of these dimensions relate to different philosophical stances. For example, a realist philosophy focuses mainly on the object (ontological dimension), while a utilitarian philosophy will focus mainly on problems, problem-perceptions, and problem-solutions. The main outtake of this is that a difference in philosophical views leads to different understandings of the term “interdisciplinarity”. The different meanings allocated to the term are irreducible to one, and so “an elimination of the plurality of “interdisciplinarity” and a unification towards one semantic core is not possible” (Schmidt, 2007, p.62). Therefore, it is important to pay attention to which philosophical connotations are assumed when using the term “interdisciplinarity” and what domain of interdisciplinarity one is discussing. As interdisciplinarity is a broad concept and essentially difficult to reduce to one meaning, it is important to clarify what definition one is basing a discussion on.

Other theories which have put interdisciplinarity forward as a relevant term are activity theory, social constructivism, and social justice theory. Activity theory is a sociocultural theory through which one investigates human activity by looking at the relationship between human activity, human consciousness, and its environmental context. In this way, activity theory allows one to study *dynamic relationships.* Thus, activity theory is useful when investigating interdisciplinary, as it promotes active learning in environments that respect student autonomy, self-directed activities allowing students to take ownership over their projects, open communication about learning strategies, and evaluation criteria focused on process rather than result (Labouta et al., 2022). Social constructivism, on the other hand, focuses primarily on the idea that each student has their own reality, and that the reality of the classroom is constructed by everyone. This philosophy emphasizes the importance of giving more space to each individual student's experiences, worldview, and competence (Flint, 2016). Lastly, interdisciplinarity has been highlighted in the context of social justice theory, as inter- and transdisciplinary focus on real-world problems rather than disciplines, and thus can move research toward the objectives of social justice (Khoo et al., 2019).

Metanalyses

During the literature search, we identified two comprehensive literature reviews discussing research done on interdisciplinary education. Similarly to us, these attempt to assess the field as a whole, and we therefore discuss them here to provide a background for our review.

Gao et al., 2020: Reviewing Assessment of Student Learning in Interdisciplinary STEM Education

Gao and colleagues (2020) present a comprehensive review of the assessment of interdisciplinary STEM education from the past two decades. From an initial library of 635 articles focusing on STEM education, they selected 49 empirical research articles. The articles were examined with the help of two dimensions developed. The first dimension concerns the nature of the disciplines being assessed and includes three categories: monodisciplinary, interdisciplinary, and transdisciplinary. The second dimension concerns the learning objectives and includes four aspects: knowledge, skill, practice, and affective domain. The results show that most assessments focused on assessments of monodisciplinary knowledge, monodisciplinary affective domains, and transdisciplinary affective domains.

Although many programs aimed to improve students' interdisciplinary understanding or skills, their assessments did not align with their aims.

The review was based on (the original) Bloom's taxonomy (Bloom et al., 1956), categorizing learning objectives into three types: the cognitive, the affective, and the psychomotor domains, though the review focused only on the cognitive and affective domains, as the psychomotor domain is not as relevant for STEM subjects. This categorization is similar to our framework, though we base our report on the revised version by Anderson & Krathwohl (2001) rather than the original version. Based on Bloom and colleagues' (1956) taxonomy, the authors define the affective domain as concerning constructs related to feelings and emotions, while the psychomotor domain deals with physically performed skills and processes. The distinction between knowledge and skills within the cognitive domain is explained as knowledge being the structured organization of concepts within a single discipline and the crosscutting concepts connecting multiple disciplines, while skills refer to the learner's ability to do something. The study concluded that most articles assessed the affective domain, and tended to focus on awareness, attitudes, beliefs, motivation, and interest toward specific disciplines in STEM. Further, despite all studies included in the review emphasizing interdisciplinarity, most studies focused on measuring students' content gain within single disciplines. Even if multiple disciplines were assessed simultaneously, they were assessed separately, and the assessment items were typically adopted from pre-existing standardized disciplinary tests. The results found in this review highlight the difficulty in assessing interdisciplinary competence, as much of the literature claims to assess interdisciplinarity while actually focusing on monodisciplinary skills.

Spelt et al., 2009: Teaching and Learning in Interdisciplinary Higher Education: A Systematic Review.

Spelt et al. (2009) present a literature review of publications on interdisciplinary teaching and learning, using Biggs' (2003) model of teaching and learning as a framework. Biggs' model conceptualizes teaching and learning as a system of four interacting components: student, learning environment, learning process, and learning outcomes. For the present review, the relevant learning outcomes were those related to interdisciplinary thinking. They defined interdisciplinary thinking as a "complex cognitive skill that consists in a number of sub-skills" (Spelt et al., 2009), based on the approach of Van Merriënboer (1997) The objectives for the review were thus identifying 1) the sub-skills constituting

interdisciplinary thinking and 2) the typical conditions that enable interdisciplinary thinking within the components of students, learning environment and learning process.

A comprehensive literature search through four databases led to the identification of 309 unique publications, 13 of which met their inclusion criteria (relevancy, peer-reviewed, language, etc.). Of these, 10 were empirical, and three were theoretical. These publications were subjected to a critical analysis, which was based on the larger review framework.

The authors identified two categories of sub-skills constituting interdisciplinary thinking: *having knowledge* and *having skills*. Within the "having knowledge" category, they identified three sub-skills: knowledge of disciplines, knowledge of disciplinary paradigms, and knowledge of interdisciplinarity. The "having skills" category consisted of 2 sub-skills: higher-order cognitive skills and communication skills.

Further, the authors identified conditions that enable interdisciplinary thinking within the components of *student*, *learning environment,* and *learning outcomes.* The specific conditions will not be listed here, but we will provide an overview of the sub-categories of conditions identified within each component. Student conditions consisted of two under-categories: personal characteristics and prior experience. Under the learning environment component, four categories were identified: curriculum, teacher**,** pedagogy, and assessment. Lastly, the learning process component contained two sub-categories: pattern and learning activities.

The literature review concludes with some of the authors' observations on the field of interdisciplinary teaching and learning in higher education, at the time of their writing. They write that previous research in this field has been limited and exploratory and that their report should be considered among the first systematic reviews of the field. Further, they argue that adopting an outcomes-based approach to reviewing interdisciplinary teaching and learning research is beneficial because it unifies the field's terminology and provides a consistent standard of assessment.

The categorization of sub-skills into *having knowledge* and *having skills* corresponds to our distinction, based on Anderson & Krathwohl (2001), between the *knowledge* dimension and the *cognitive processes* dimension of the cognitive learning domain. Our report also reflects the finding that most of the literature within the field is exploratory and that it lacks controlled research: this, we contribute in part to the "Scholarship of teaching and learning" (ref. Boyer, 1990) tradition of research. We will discuss this further in our conclusion.

The Utility of Interdisciplinary Education

Our report is mainly a review of methods for measuring and executing interdisciplinarity. We recognize, however, that implicit in this pursuit is the assumption that interdisciplinarity is of value to educational settings and therefore worth addressing. In this section, we look at research on the value of interdisciplinarity in education, to provide a normative grounding for our descriptive review of methods for measuring and executing interdisciplinarity.

Conceptual Arguments for Interdisciplinary Education

Much of the literature on this topic is theoretical in nature. Brassler & Dettmers (2017), for instance, present three main reasons for addressing interdisciplinary competence: 1) Interdisciplinary competence promotes a holistic view on theory and knowledge development, and goes in line with up-to-date scholastic training in academia; 2) Organizations have shown increased interest in interdisciplinary competence, as future projects and tasks are becoming more complex; and 3) Interdisciplinary competence is needed to address the “grand challenges" of our time, as these cannot be solved within one discipline. Larsen (2018) suggest that there are two main reasons for the rise in interest in interdisciplinarity in the last 30-40 years: Firstly, an inside reaction to the “narrow academic parochism” and lack of innovation within the separated disciplines has led to the rethinking of the self-definition of disciplines, their theories, methodologies, etc.; and secondly, the complex challenges of today’s world, such as globalization, climate change and emerging technologies, require solutions that cannot be provided by single disciplines. Khoo et al. (2019) argue that inter- and transdisciplinarity can move research toward the objectives of social justice, as its focus on problems rather than disciplines provides ways of addressing real-world issues that transgress traditional disciplinary boundaries. Inter- and transdisciplinarity are also able to bring forward underrepresented perspectives from within and outside academia, thus challenging dominating narratives.

Empirical Studies Supporting Interdisciplinary Education

Some empirical research has been done on the connection between interdisciplinarity in education and educational outcomes. Wright (1992) studied the relationship between interdisciplinary coursework and intellectual development, as assessed by students’ movement from dualistic to relativistic thinking (Perry, 1970, 1981), and she found that the number of interdisciplinary general education courses taken by students was a strong predictor of their intellectual development. Similarly, Pierrakos and colleagues (2007)

presents an empirical study on the differences in educational outcomes between engineering students participating in single- and interdisciplinary team design projects, and they found that interdisciplinary teamwork had an overall positive impact on the educational student outcomes of team-design projects, especially when it came to "technical" learning outcomes. Lattuca et al. (2017) also conducted an empirical study on the differences in learning outcomes between students in disciplinary vs interdisciplinary majors in an undergraduate. Unlike the two previous studies, however, they found that there was little difference in educational outcomes between the group. Students in interdisciplinary majors reported *less* change in critical thinking and *need for cognition*, defined as their "tendency to enjoy effortful cognitive activity" (Cacioppo et al.,1996), than did students in disciplinary majors.

A study by Bear & Skorton (2019) looked at the relationship between interdisciplinarity and the job market. Reviewing surveys of employers on the qualities they looked for in job applicants, they found that some of the most sought-after qualities were qualities typically associated with interdisciplinary approaches to teaching and learning, such as critical thinking, teamwork skills, and the ability to apply knowledge to real-world settings. This indicates that interdisciplinary educational approaches are suited to prepare students for today's job-market. Empirical research has also been done on the general scientific impact of interdisciplinarity (Okamura, 2019; Molas-Gallart et al., 2014), as well as its impact on specific real-world issues such as climate change (Song et al., 2023) and cancer care (Tremblay et al., 2011). The identified articles on these issues all regard the impact of interdisciplinary research rather than interdisciplinary education, however, making them less relevant for our purposes.

We conclude this section with some general observations of the field of research into the value of interdisciplinary education, and some suggestions for further research. We find that arguments in favour of interdisciplinary education tend to relate to the areas of *educational outcomes*, *real-world impact,* and *academic evolution/disruption*. A potential fourth area is *employment prospects*, but one could argue that this falls under educational outcomes and/or real-world impact. Some empirical studies have been done on the relationship between interdisciplinarity and educational outcomes, but these are few and often limited in scope. We see potential for further research on this topic, especially large-sample controlled studies. Lattuca et al. (2004) came to a similar conclusion regarding the lack of empirical research on the impact of interdisciplinary education on learning outcomes, and they proposed a research agenda consisting in researchable questions. These questions can be used as a basis for future research. Lastly, advocates of interdisciplinary education often

assert that interdisciplinary education produces students capable of addressing complex real-world issues, but we could not identify any empirical evidence which supports this proposition. Longitudinal studies on the real-world impact of interdisciplinary education are therefore called for.

Measuring interdisciplinarity

Both in order to assess student accomplishment in interdisciplinary programs, and in order to evaluate and compare such activities themselves, one needs standards of measuring students' levels of interdisciplinary competence. In this section, we first provide an overview of qualities which are described in the literature as potential indicators of interdisciplinary competence in students. We then go on to describe some comprehensive frameworks and measurement instruments that have been proposed. These, we divide into 1) frameworks for measuring interdisciplinarity in activities, which we believe are best suited for evaluating and comparing the success of interdisciplinary programs, and 2) frameworks for measuring interdisciplinary competence in students, which can be used for assessment and grading purposes. In reality, there is significant overlap between these categories, as the levels of interdisciplinary competence in the students are likely to reflect the levels of interdisciplinarity in the activity. We choose to distinguish between them, however, because some approaches to measuring the interdisciplinarity of activities are ill-suited to the assessment of students, particularly those that rely on self-reports of perceived competence.

Indicators of Interdisciplinary Competence

Several potential indicators of interdisciplinary competence in students have been highlighted in the literature. We present these here in terms of the learning dimension(s) (cognitive, knowledge, affective) we see them as most related to.

We found that most of the indicators relate wholly or partly to aspects of the cognitive process dimension in the revised taxonomy. A recurring ability is *critical thinking* (Newell, 1998, 2002) with variations such as *critical awareness* (Boix Mansilla et al., 2000), and *critical argumentation* (Wolf & Haynes, 2003a/2003b). Though critical thinking and its variations are defined slightly differently in these cases, they all relate to the cognitive processes dimension, as they concern *evaluation* (critique), *understanding* (interpreting, summarising, etc.), and/or *attribution* (deconstruction). Another key ability recognised is *integration:* Kovalovsky (1979) describes integration of knowledge as being a key feature of interdisciplinary education; and interdisciplinary integration is one of four sources of interdisciplinary competence in Wolf & Haynes' (2003a, 2003b) scoring rubric. Additionally,

Boix Mansilla et al. (2000) recognizes *advancement through integration* as a main factor in their framework, and Newell & Green (1982) suggest that *synthetic reasoning* is the most important ability for interdisciplinary competence. Integration is recognized as an aspect of the organize sub-category of the cognitive processes dimension in the revised taxonomy. *Reasoning by analogy* and *deductive reasoning* are proposed by Newell & Green (1982) as key abilities in interdisciplinary competence. We view these abilities as related to summarizing and inferring, which are part of the understanding sub-category in the cognitive processes dimension. Finally, Kovalovsky (1979) presents *innovation* as a factor relevant to interdisciplinary competence, which relates to the creation aspect of the cognitive process dimension.

Within the knowledge domain, we identify two potential indicators of interdisciplinary competence. These are *knowledge of multidisciplinary perspectives* and *disciplinary grounding*. Lattuca et al. described interdisciplinary abilities as being the "capacity to recognize, evaluate, and use differing (multiple) perspectives" (2004, p. 44). The ability to recognize multidisciplinary perspectives is also emphasized by Wolf & Haynes (2003a, 2003b). These abilities relate partly to the cognitive domain, as they regard evaluation and application of multidisciplinary perspectives. We see them as also related to the knowledge dimension, however, as having factual knowledge is necessary to evaluate and apply it. Moreover, some articles highlight *disciplinary grounding* as necessary for interdisciplinary competence (Boix Mansilla, 2000; Wolf & Haynes, 2003a, 2003b), which concerns the possession of factual, conceptual, and procedural knowledge within one's discipline. However, the utility of interdisciplinary grounding is a topic of controversy in the literature (Schijf et al., 2022), which will be further explored later in the report.

Some indicators highlighted relate to emotions and attitudes and are thus related to the affection dimension. Lattuca et al. (2012) highlights appreciation of disciplinary perspectives as a factor of interdisciplinary competence, saying that "an appreciative attitude towards other 'stories' and disciplinary frames of reference" is necessary to develop interdisciplinary competence (Nikitina, 2005, p. 413, as referenced in Lattuca et al. 2012). They also appreciation of perspectives from outside academia as a dimension of interdisciplinarity, though, as they point out, this relates more strictly to transdisciplinarity (Lattuca, 2012). Another indicator that can be viewed as partly affect-related is *sensitivity to bias and ethical issue*s (Newell, 2002). This relates in part to the cognitive process dimension, as we can see by looking at the description of the attribution aspect of the analyze sub-category of the cognitive process dimension: "determine a point of view, bias, values, or intent underlying

presented material (…)" (Anderson & Krathwohl, 2001). Depending on how one defines sensitivity to bias and ethical issues, however, one could also view it as an attitudinal quality, or one which requires an emotive component.

Frameworks for Measuring Interdisciplinary Competence

Frameworks for Measuring Interdisciplinarity in Activities

In this section we focus on proposed frameworks and instruments for measuring interdisciplinarity in programs. These can be applied for evaluation of and comparison between programs, as well as in empirical research on methods of executing interdisciplinary activity. We discuss three instruments: the Interdisciplinary Education Perception Scale (IEPS), the Modified IEPS, the Interdisciplinary Understanding Questionnaire (IUQ), and the Self-Report scale of Interdisciplinary Competence.

The IEPS was developed by Luecht et al. (1990), and aims to measure interdisciplinarity in health professions through assessing students' perceptions of their possession of four attitudes which the researchers identify as important to interdisciplinarity (based on findings from Bassof (1983) who outlined four attitudes important for interdisciplinary service and cooperative efforts):

1. professional competency and autonomy
2. perceived need for professional cooperation
3. perception of actual cooperation and research sharing within and across professions
4. understanding the value and contributions of other professionals/professions.

The questionnaire includes 18 items and was validated by five faculty researchers through a consensus approach before being distributed to a total of 143 subjects, where 118 subjects were undergraduates.

McFadyen et al. (2007) pointed out several flaws in the development and final product of the original IEPS by Luecht et al. (1990), including, but not limited to: the limited sample size (143 subjects, of which only 118 were undergraduates); the transfer of individual-factor-weights to the composite of factors in their linear regression; a lack of reporting on reliability other than internal consistency (such as test-retest reliability); and low (alpha values below 0.60) internal consistency values of three of four factors. Therefore, after several rounds of reliability tests done on a larger sample group, they proposed a modified IEPS. The main difference from the original IEPS is the deleting of the fourth subscale "understanding the value and contributions of other professionals/professions", and different weighting of items to each subscale. The modified IEPS shows greater reliability and alpha values than the

original IEPS. Therefore, the revised IEPS is likely to be a more reliable and generalizable measure of interdisciplinarity than the original one.

Note that both the IEPS and the modified IEPS are aimed at developing an assessment form for students within health professions, to better foster later interprofessional cooperation within health care. This might have affected the understanding of interdisciplinary competency, and consequently what these scales are measuring. Besides this, neither articles properly define what they mean by interdisciplinarity. Both versions of the IEPS relate to the affective domain, as they assess students' *attitudes* towards their own and other disciplines.

The Interdisciplinary Understanding Questionnaire (IUQ), developed by Schijf (2022), is based on the finding of Spelt et al. (2009) that interdisciplinary understanding can be measured in terms of *knowledge* and *skills*. The questionnaire thus addresses parts of both the knowledge and the cognitive process dimension; apart from *collaboration skills*, the sub-skills they highlight all fall under the cognitive process umbrella of the taxonomy. The survey was intended as a general instrument to measure students' generic interdisciplinary progress, to effectively measure the success of interdisciplinary programmes. The study builds on Boix Mansilla's (2000) definition of interdisciplinarity, and views interdisciplinary education as "one promising teaching approach that prepares students for participating in a complicated world", preparing students to deal with future complex issues which cannot be dealt with through monodisciplines alone, and educating future (research) leaders.

The questionnaire was developed through testing on a total of 505 students, where about half of the students were participating in an interdisciplinary program. The resulting instrument is a second-order model consisting in two higher factors – *knowledge* and *skills*, 6 sub-factors and 24 total items. It consists of 27 self-report items answered on a Linkert scale. The items of the IUQ measures students': *knowledge of different disciplinary paradigms, knowledge of interdisciplinarity*, (*critical) reflection skills*, *communication skills*, and *collaboration skills*. The test values of the IUQ indicate that it can be an accurate measurement of interdisciplinary understanding in higher education. The researchers note that there are some limitations to the study, as the students sampled are high-achieving students and may therefore perform differently to other students. Further, all students were first-year students with no previous exposure to interdisciplinarity, and the findings are all based on measurement invariance. Longitudinal research is wanted to gather actual data on interdisciplinary literacy as well as further testing the model.

The Self-Rapport Scale of Interdisciplinary Competence, developed by Lattuca et al. (2012) is a survey-based instrument for measuring interdisciplinary competence in higher education,

designed to assess the success of interdisciplinary educational programs. It consists or three scales: “Interdisciplinary Skills”, “Reflective behaviour”, and “Recognizing Disciplinary Perspectives”. The scale was subjected to two rounds of testing, where the second round was done on a large sample size (n = 32,737, response rate = 5,249). It shows high internal consistency and low correlation with other scales. While it was primarily developed for and tested on engineering students, there might be potential for its use for measuring interdisciplinarity in other fields of study.

The development of this scale builds on a definition of interdisciplinarity as “a process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession...and [that] draws upon disciplinary perspectives and integrates their insights through the construction of a more comprehensive perspective”. The survey items were informed by a comprehensive review of the literature on interdisciplinarity, which resulted in 8 dimensions of interdisciplinarity: 1) awareness of disciplinarity; 2) appreciation of disciplinary perspectives; 3) appreciation of non-disciplinary perspectives; 4) recognition of disciplinary limitations; 5) interdisciplinary evaluation; 6) ability to find common ground; 7) reflexivity; and 8) integrative skill. Together, these dimensions relate to all three domains in our general framework: the cognitive, affective, and knowledge domain. The same broadness of approach is reflected in the final survey items.

Frameworks for Measuring Interdisciplinary Competence in Students

Two of the articles further propose assessment frameworks for scoring students’ level of interdisciplinarity. Wolfe & Haynes' construct validation of a scoring rubric for expository, research-based interdisciplinary writing (2003a; 2003b). The rubric outlined 55 criteria, under the categories of *drawing on disciplinary sources*, *critical argumentation*, *multidisciplinary perspectives*, and *interdisciplinary integration*. In its initial incarnation, the rubric elicited high interrater reliability and was clearly able to distinguish well-written disciplinary texts, from well-written interdisciplinary texts. The model of evaluation by Boix Mansilla et al. (2000) contains three components: d*isciplinary grounding*, *advancement through integration*, and *critical awareness.* The model was based on the empirical research of 69 in-depth interviews of interdisciplinary teachers, as well as classroom observations and examination of student work, and was later applied to 40 pieces of student work. Both the framework by Wolfe & Haynes’ (2003a; 2003b) and that by Boix Mansilla et al. (2000) assesses the *cognitive* and *knowledge* dimensions of interdisciplinarity, while neither assesses the *affect*

dimension. This might reflect the difficulty of evaluating students' attitudes or emotional states without relying on self-assessment.

Discussion Regarding How to Execute Interdisciplinary Activity

Should Interdisciplinary Learning be Grounded in Disciplinary Knowledge?

As identified by Schijf et.al (2022), there is a disagreement in the literature on whether disciplinary grounding, defined by Boix Mansilla & Duraisingh as "the degree to which student work is grounded in carefully selected and adequately employed disciplinary insights …" (2007, p. 222), is beneficial and/or important to interdisciplinary education. In this section, we present some of the main arguments to outline and assess the debate.

The main disagreement seems to concern whether the development of a disciplinary vocabulary and/or cognitive maps in students presents insurmountable barriers to interdisciplinarity. Bialek & Botstein (2004) see the early emergence in students of disciplinary barriers as a reason for introducing interdisciplinarity early rather than waiting until the students are more advanced and therefore more disciplinary in their perspective. Davies & Devlin (2007) also see the development of disciplinary language and/or cognitive maps as a potential hindrance to interdisciplinary learning, but they see such development as essential for producing graduate students capable of conducting domain-specific research. They argue that disciplinary barriers to a large degree can be mitigated through preparatory measures such as student mentorships and bridging programs. Griffiths (2022), on the other hand, argues that truly interdisciplinary activity involves a conversation between multiple disciplinary perspectives. Since undergraduates at the early to middle stages of their education have not yet developed disciplinary perspectives, they can therefore not engage in true interdisciplinarity.

Some empirical studies have been conducted on this matter. Boix Mansilla & Duraisingh (2007) conducted a survey of experienced faculty on the qualities they saw as most important in interdisciplinary student work. 75 % of faculty agreed that disciplinary grounding, as defined above, is necessary for good student work. Faculty argued that having a basic understanding of disciplinary content is necessary for drawing connections between disciplines, and that without disciplinary grounding, there is a risk of the education becoming "a mile wide but an inch deep" or "a light educational experience" (Boix Mansilla & Duraisingh, 2007). Another empirical study, conducted by Remington-Doucette et al. (2013), assessed the impact of an interdisciplinary introductory sustainability course on a class of students with different disciplinary backgrounds. Their results indicate that students with a

strong disciplinary grounding/affiliation have a greater capacity for learning in interdisciplinary programs, than students without such an affiliation.

The limited empirical evidence that exists thus suggests that having at least some disciplinary grounding is beneficial to interdisciplinary learning. Further research on the topic is warranted, however, especially controlled, large-scale studies, as this is currently lacking.

Reflections on the Execution of Interdisciplinary Activity

Course Development

Some of the literature regards the process of development of interdisciplinary courses, either consisting of concrete development methods or more general advice based on experiences with course development. Skywark et al. (2022) describe the application of "design thinking" - a design process consisting of the three phases of inspiration, ideation, and implementation - to the construction of an interdisciplinary course. Central to their course development was engagement with stakeholders in the ideation phase. Here, they interviewed design thinking faculty and experts, as well as graduate students, about their experiences, interests, and needs. The authors write that the design thinking process can be especially useful for faculty who "desire student engagement in the classroom because it involves stakeholders from the beginning, ensuring their articulated and unarticulated needs are met" (Skywark et al., 2022).

The role of student influence on course design and development is emphasized also in the article of Nielsen et al. (2022), who advise instructors to remain flexible and alter the course plan in accordance with student needs. They found that feedback on student's level of knowledge integration was especially constructive, as this indicated to the faculty how much time they should spend on multidisciplinary vs. Interdisciplinary teaching. At the same time, Shibley (2006), argues that ample *planning time* is the most important factor contributing to the success of team-teaching efforts. Adequate planning time allows for negotiation between differences in outlooks and approaches, he argues, which should be figured out before teaching begins. The advice of Nielsen et al. (2022) to remain flexible and Shibley's (2006) advice to plan comprehensively may seem contradictory at first glance, but this is not necessarily the case. One can plan for flexibility - for example by leaving open rooms in the plan or planning in branch-like structures where possible courses of action correspond to different likely outcomes.

Course Formats

Several course formats are described in the literature. We classify these as *lecture-based* courses, *project-based* courses, and courses that combine these two approaches.

Lecture-based courses as we define them are courses where the primary component is a series of lectures and/or classroom seminars. These might include project work, but if so, it will be a minor component, typically for assessment purposes. Most of the articles included are case studies or experiential studies which the authors reflect upon in their articles, and a few articles are based on observation of students' performance.

Lecture-based courses generally expose disciplinary students to multidisciplinary knowledge and vocabulary through focusing on an issue that is interdisciplinary in nature. An example of a lecture-based interdisciplinary course is "Great Modern Revolutions" (Barisonzi & Thorn, 2003): a course which, through a series of lectures, examined the topic of revolutions from the disciplinary perspectives of history and literature. Similarly, Larripa & Mazzag's (2016) created a mathematical modeling course for biology students, where lectures were held by experts in biology followed by student-led paper presentations on articles addressing biological problems using mathematical and computational tools. Moreover, Agllias et al. (2021) described a course for social work students, which incorporated diverse disciplinary perspectives, such as psychology, sociology, law, and ethics integrated through simulation learning. The researchers found that interdisciplinary learning, even within a disciplinary setting, was found to enhance the students' soft skills, such as problem-solving, collaboration, active listening, and empathy.

Project-based courses, on the other hand, consist primarily in project work, with little to no theoretical teaching involved. Courses like this generally focus on placing students from different disciplines in interdisciplinary groups and giving them a task, normally a real-life issue, which they need to work together and cooperate on. The students gain interdisciplinary competence and vocabulary indirectly through this group work. Examples of such courses include a project which combined English and Theatre studies through the method of "devising" (Mahoney & Brown, 2013), an innovation sprint combining Doctor of Pharmacy students and Master of Public Health students (Kruger et al., 2023), as well as a 2-year combined Marketing and Sustainability course which centered around an experiential service-learning project (Wiese & Sherman, 2011). Moreover, a study, on how to build trust within interdisciplinary or interprofessional teams was executed by Liu (2021). Liu studied 275 nursing and design students attending parallel courses, one containing interdisciplinary teams and one with non-interdisciplinary teams. The study recognized that interaction behaviors, constructive controversy, helping behaviors, and spontaneous communication were all positively correlated with cognition-based trust, which leads to better team outcomes and collaboration. However, team interdisciplinarity negatively moderated the correlation

between constructive controversy and cognition-based trust and had no effect on the other two behaviors.

Most articles identified in this section describe courses that combine lectures and project-based work, usually moving from theoretical foundations towards practical application in a project. An example of this type of course is a food and nutritional security course described by Knobloch et al. (2020) in which students followed a series of multi-disciplinary lectures, before being placed in interdisciplinary groups where they conducted assessments of the nutritional security in local communities, as well as created video-learning content on the topic. Further examples include an integrated Sociology and Political Science course on the topic of Globalization, which moved from multidisciplinary through interdisciplinary teaching and culminated in a community-based visual ethnography project (Nielsen et al., 2022), an applied statistics course which shifted continually between theory and application (White, 2019), and a virtual Engineering Design collaboration between an Indian and German research university which, though largely project-based, also introduced students to theoretical perspectives from Feminist Science and Technology Studies and methods from Participatory Design (Buchmüller et al., 2021).

All the studies described in this section appear to have been successful (based mostly on reflection- or survey-based data), indicating that there is no right or wrong format for interdisciplinary courses. The prevalence of courses that combine theory and practical application, however, might suggest that this format lends itself to interdisciplinary activity. A potential benefit of a combined approach is that it could help avoid dissension between students from different disciplines (Nielsen et al., 2022) by introducing them to relevant perspectives from the other discipline(s) before asking them to apply and integrate their knowledge in interdisciplinary groups. It is unclear, however, whether such dissension would emerge between students who lacked multidisciplinary grounding. A study by Liu (2021) suggests that introducing constructive controversy early on, (i.e., fostering discussions between students with contrasting ideas, theories, and opinions in order to seek agreement and a collective judgment) has a negative effect on interdisciplinary trust and collaboration and therefore should be introduced later on in the process. However, in the combined English and Theatre course described by Mahoney & Brown (2013), students from the two majors went straight from separated classes into interdisciplinary collaboration, without any preparatory introduction into the other discipline. The authors report that the students naturally developed the other discipline's vocabulary and perspective – a finding that casts doubt on the notion that multidisciplinary instruction is necessary to avoid dissension in

interdisciplinary groups of students. Levels of dissension might also depend on the disciplines involved, students' motivation, and the stage of education students are at, along with other factors.

As the literature is conflicting, it might be worth reflecting on what format will best serve one's course goal. Lecture-based courses might be better suited for developing interdisciplinary *knowledge* in students, as such courses typically regard confined interdisciplinary topics, whereas project-based courses, in which students apply and integrate their knowledge in practical settings, might to a larger extent develop students' skills by addressing the factors in the *cognitive process* dimension. This divide can be found in the literature, where some articles focus on interdisciplinarity as knowledge taught explicitly to students by an instructor, while others focus mainly on interdisciplinary skills gained indirectly through group work and cooperation between students from different disciplinary backgrounds.

Moreover, it is important to be aware that some of these articles use *multidisciplinary* or *interprofessionalism* as a synonym for interdisciplinarity. For example, when Wiese & Sherman (2011) discuss interdisciplinarity, it is relevant to note that they in their study compartmentalizes both the disciplines and the students, and therefore do not integrate the disciplines into a synthesized whole. Further, in Larripa & Mazzag's (2016), Kruger et al. (2023), Liu (2021), and Agllias et al. (2021), we find that interproffesionalism is used synonymously for interprofessionalism. Within these studies, the aim is to provide students with the tools needed for later interprofessional cooperation. Thus, interdisciplinary education is used to provide students with relevant vocabulary and communication and cooperation skills, preparing them for a specific career, rather than focusing on *interdisciplinary competence* as such. Similarly, the Interdisciplinary Education Perception Scale (IEPS) (Luecht et al., 1990) and the Modified IEPS (McFayden et al., 2007), are frameworks for assessing interdisciplinarity in education of student within health professions, aimed at evaluating skills and competence for future interprofessional collaboration. We have included these articles in the report as they claim to do interdisciplinarity, and to some extent to focus on interdisciplinary education, but one should be aware that there is a controversy regarding whether interdisciplinarity and interprofessionalism can be discussed together.

Challenges Faced When Doing Interdisciplinarity

Multiple research articles discuss the challenges one faces in the development of interdisciplinary education (Björklund et al., 2013; Carell et al., 2020; Nielsen et al., 2022;

Barisonzi & Thorn, 2003; Gardner et al. 2014). An ongoing theme is the challenges the faculty faces when attempting to implement interdisciplinary methods or courses within disciplinary university systems. This is described by the Sino-Finnish teaching initiative aimed at promoting interdisciplinary hands-on teaching and enabling teachers to implement their teaching ideas despite facing challenges in implementing innovative practices within established systems (Björklund et al, 2013). They recognize the same challenges for teachers in Finland and China, and highlights among other inflexible curriculum, large class sizes and lack of adequate resources as main challenges (Moore et al., 2007, as cited in Björklund et al., 2013). They also recognize challenges with moving teaching activities 'out of the classroom' and in implementing experimental teaching methods, even though these ideas can merit further development and long-term pedagogical training, which is something that the relevant universities request. Institutional barriers which can make the implementation of interdisciplinary activities difficult are also discussed by Carrel with colleagues (2020). They highlight the balancing of schedules, the distribution of credit and compensation among the instructors of the course, lack of overall resources, and lack of resources and/or faculty within relevant fields.

Another challenge concerns how to teach interdisciplinarity to students. Some of the articles discuss how students can successfully integrate multidisciplinary knowledge into an interdisciplinary view (Carell et al., 2020; Nielsen et al., 2022; Barisonzi & Thorn, 2003). Thus, articles argue that students need guidance on how to connect knowledge from different disciplines, and that the teacher or lecturer's job is to make these connections explicit for the students. Barisonzi & Thorn (2003) gives an example of this, as they compare two years of the same course "Great Revolutions". As they find that students struggle to integrate the perspectives of different disciplines on the same topic themselves, they made several changes to the course. Firstly, they restructured the course so that the disciplines were more integrated: whereas before they had first spent weeks studying revolutions from one disciplinary perspective before moving on to the next, they now studied disciplines side by side with a themed focus, which made interdisciplinary connections more explicit. They also allowed for more time for discussion around these recurring themes. These changes seem to have been successful, as students in the second course round produced work that integrated and synthesized knowledge from the two disciplines.

Another study discussing the challenges of interdisciplinarity is Gardner et al. (2014), who focuses on the socialization of faculty and students to interdisciplinarity. They propose challenges with faculty's balancing of time and resources, as time pressure often led to

faculty being absent and meeting the challenges of interdisciplinary teamwork as time constraining hinders rather than learning opportunities. Faculty were less motivated to work with interdisciplinarity and were less shaped by the experience. However, this could both be due to their previous disciplinary grounding or due to time constrains. The article further shows how faculty claiming to have interdisciplinary experience and insight, only had experience with collaboration, or at best multi-disciplinarity. Another valuable insight from this article is the challenges doctorial students meet when following an interdisciplinary path. Interdisciplinary students, in contrast to traditional, disciplinary students, need to learn a much larger amount of relevant terminology and disciplinary knowledge, much build a larger network, and lack professors with the actual interdisciplinary competence to guide them. In the project described by Gardner and colleagues (2014), students ended up relying more on the guidance and support of each other than of faculty, due to the faculty's time restrictions and lack of interdisciplinary competence.

Lastly, there are several challenges regarding research on interdisciplinarity. Although most of the articles included in this report belong to the tradition of scholars of teaching and learning, some articles are more observation based and attempt to gather data systematically (eg. Larripa & Mazzag, 2016; Agllias et al., 2021; Kruger et al., 2016; Liu, 2021). However, research on interdisciplinarity tend to be done on small sample sizes, and on self-selecting students, either based on interest for interdisciplinarity or on high achieving students with high grades and academic skills. Therefore, the samples tend to be skewed and not generalizable. Replications of studies on other samples is therefore requested, and some propose that replications should be done over longer periods of time and with larger sample sizes.

Advice for Further Execution of Interdisciplinary Activity

Some of the articles propose advice future development of interdisciplinary courses. For example, Barisonzi & Thorn (2003) concluded their study with five remarks. Firstly, *do not compartmentalize the course.* Rather integrate the different disciplines into a synthesized and coherent whole, as this will help the students to draw disciplinary connections and see the bigger picture. Secondly, *know your audience.* The course must continually adapt in accordance with the needs of the student group. Third is *objectivity is a myth.* Instructors must recognize that all teaching is coloured by the biases and assumption of the teacher. Therefore, they should strive be open about their own views without projecting these views onto the students. The last two is *details matter,* as seemingly small details in the content or

structure of the course can make a significant difference in the overall course deliverance, and to *learn to live with* ambiguity, as developing interdisciplinary thinking means moving away from simple causal relations towards complexity and degrees of uncertainty.

White (2019) also outlines methods for enhancing interdisciplinary education. In developing the course material, he recommends *collaboration with faculty.* Involving faculty members from different departments, they ensured that the course would be relevant for students form all disciplines. Secondly, he emphasizes *project-based learning* and *emphasis on real-world examples.* Allowing the students to work together and apply their knowledge to real-world projects enhance their interdisciplinary understanding. Lastly, White (2019) highlights the importance of focusing on teaching the students *transferrable skills,* such as communication beyond disciplines.

A third article that puts forward recommendations on how to structure interdisciplinary education was written by Shibley (2006). Shibley concludes with five concrete recommendations for developing and delivering team-taught courses, which concern: 1) communication between teachers, 2) knowledge integration, 3) transparency around assessment methods, 4) distribution of individual tasks rather than roles, and 5) adequate time for planning. Communication among teachers is important as open discussion of pedagogical methods and philosophical views may reveal differences in approaches which may generate conflict. Such discussion is especially important in the planning stages, as the teachers at this stage can plan for and around their differences. Transparency around choices is also important when a course is thought by different teachers, as different choices can seem puzzling to students. Further, teachers should collaborate dynamically, and rigid roles therefore seem unfitting. Lastly, Shipley argues that adequate time for planning is the most important factor and that collaborators should be chosen based on their willingness to invest time in the project. Adequate planning time allows for negotiation between differences in outlooks and approaches, which should be figured out before teaching begins.

Conclusion

In conclusion, the field of interdisciplinary education research consists largely of reflections and exploratory studies, and potential controlled quantitative or qualitative research is yet to be executed. Although some studies are more systematic, the literature is to a large degree based on smaller and non-randomized samples, from classes consisting of few students who usually are self-selecting. Most of the literature included in this report falls under the tradition of Boyer's (1990) scholarship of teaching and learning (SoTL), according

to Boyer's idea of the professoriates' four scholarships. These are reflections and observations done by scholars and educators, on their courses to advance and better their teaching and share knowledge and experiences with other scholars. This tradition has been important for the advancement of teaching and can be of quality for inspiration regarding developing interdisciplinary educational courses. However, these articles cannot be considered as experimental evidence or researched findings, due to its lack of systematic rigour. Within the literature we have read, there is a lack of experimental and qualitative research which can say something general about interdisciplinary education and competence.

Another issue with the literature, is the lack of a common definition of interdisciplinarity and related concepts. Moreover, we find that definitions are rarely placed within a holistic framework, which makes it difficult to compare them to each other or link them to the remaining body of pedagogical literature. Some literature reviews (Gao et al., 2020 & Spelt et al., 2009) attempt to categorize definitions in terms of learning domains. In our review we utilize the revised Bloom's taxonomy of Anderson & Krathwohl (2001) in order to contextualize, deconstruct and analyze explicit and implicit conceptions of interdisciplinarity and related concepts. We also found that many articles never define interdisciplinarity at all. As the concept of interdisciplinarity is far from self-explanatory, this leads to uncertainties and misconceptions within the literature as to what the articles are actually discussing and what the scales and frameworks are actually measuring. Further, interdisciplinarity is often mistaken for multidisciplinary or interprofessionalism, and thus we can question whether many articles claiming to study interdisciplinarity actually do so.

In the report, we make several distinctions. Firstly, we make the distinction between studies on assessment and evaluation of interdisciplinarity in programs and in students on one side, and discussions on how to execute interdisciplinary activity on the other. We further make a distinction between interdisciplinarity in programs and interdisciplinarity in students, but this is a blurred rather than definite distinction, as the levels of interdisciplinarity in students will often reflect the levels of interdisciplinarity in programs. When discussing literature on the execution of interdisciplinary activity, we take a thematic approach, separately discussing course development, course formats, challenges of interdisciplinary and advice for further execution of interdisciplinarity. Although this sectionalisation represents only one possible way of doing things, we found it a helpful basis for approaching the vast and varied body of literature on the topic of interdisciplinarity.

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