Reflecting on the value of mathematics in an interdisciplinary STEM course

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Rationales for interdisciplinary STEM courses are often based on the fact that the problems we face in today's world call for perspectives and knowledge from many different areas. In many cases this includes mathematics because it is used in many research fields and because it is part of everyday life. At the same time interdisciplinary literature suggests that mathematics gains the least from integration. In this paper we use a successful interdisciplinary STEM course in the Netherlands to illustrate how students and teachers think about the value of mathematics. To analyse teacher and student statements concerning the value of mathematics a model is introduced for a disciplinary mathematics perspective for interdisciplinary STEM courses and the opportunities this model can provide are discussed.

Keywords: Mathematics in STEM, secondary education, value of mathematics, perspective taking

Introduction

While studying epithelia tissue and the shapes of the epithelium cells in animals, biologists had questions about the shapes of densely packed cells in curved layers. Sharing their questions with mathematicians, these formalised it as a precisely defined new shape. Computer scientists then programmed the shape as a computer model, which was analysed by physicists, who confirmed the shape would be stable packed at the scale of epithelial cells. Knowing what to look for, biologists then found the modelled shape (Parker, 2018).

This example of the finding of the new mathematical shape called the scutoid is an example of how disciplines work together to solve a problem. Looking specifically at the role of mathematics it became clear that mathematical knowledge was used to model and predict a possible shape and that it therefore played a valuable role in the research process.

In general, mathematics is used in many research fields and is part of everyday life. According to the National Research Council (2013, p.2) the mathematical sciences are "becoming an increasingly integral and essential component of a growing array of areas of investigation in biology, medicine, social sciences, business, advanced design, climate, finance, advanced materials, and many more". The Dutch branch of Deloitte tried to quantify the contribution of mathematics to the Dutch economy (Deloitte, 2013). They found that the full time equivalent of about 900,000 highly educated employees use mathematical sciences in the Netherlands, 11% of total employment and 35% of higher education employment in the Netherlands. "They include scientists, who use mathematics all the time, as well as bankers, who spend some of their time computing the value of assets, and physicians, who use maths to interpret medical tests" (p.5). These examples indicate that mathematics is seen as valuable for society because of its frequent use.

In both reports recommendations are made about mathematics education, stating that it should reflect the development and stature of the field to have "more and better usage of mathematical sciences" (Deloitte, 2013, p.21). One way to show the use of mathematics is through interdisciplinary educational courses that require mathematics and other disciplinary knowledge to solve real-life problems, such as the epithelia problem.

In literature, such as that mentioned above, we keep coming across phrases that contain the words 'use' of mathematics and the 'value' of using mathematics. These two concepts 'using' and 'valuing' mathematics seem connected and therefore worth a closer look. In this paper we examine the distinction and the relationship between these concepts and we use the interdisciplinary STEM course NLT in the Netherlands as a case study to illustrate a model of disciplinary perspective.

Background of NLT

The Dutch curriculum for upper secondary education contains a course called 'Nature, life and technology' (NLT). Since its introduction in 2007 at pre-university and higher general level, the general aims of this elective interdisciplinary STEM course are to let students experience the importance of interdisciplinary coherence in the development of science and technology and to increase the attractiveness of science education for students (Stuurgroep NLT, 2007). The course is intended as a supplement to the existing disciplines in the Dutch curriculum: physics, chemistry, mathematics, biology and physical geography. It aims to offer both a broader and more in-depth educational programme for science and mathematics and is not meant as a replacement of other courses.

Within the boundaries of an examination programme teachers construct their own curriculum and can select teaching materials from a wide range of small booklets, called *modules*. Each module introduces a contemporary, context-oriented science problem that can only be solved by involving different (disciplinary) perspectives. As a consequence, it is preferred that the course is taught by a team of teachers, preferably representing the relevant disciplines. In the Netherlands such a team is called a NLT-team.

In the examination programme of NLT the nature of the course is made explicit by formulating four characteristics which should be visible throughout the curriculum (Krüger & Eijkelhof, 2010). The nature of NLT is characterized by attention to 'interdisciplinarity', 'the relationship between science and technology', 'the orientation on higher education and occupations' and 'the role of mathematics in science'. Concerning the 'role of mathematics in science' it is said that NLT shows how mathematics is used in the sciences. However, how this should manifest itself is not clear (den Braber, Krüger, Mazereeuw & Kuiper, 2019). Our study shows that more than 20% of students doesn't mention mathematics when asked about the disciplines that play a role in NLT. When asked why mathematics is not a part of NLT some say that only low-level mathematics is required, or that it is not similar to what they do in mathematics class. Besides this, the research shows that mathematics teachers seem to struggle more with their role in NLT than science teachers. Besides this, the added value of having mathematics teachers in an NLT-team is not always clear. When it comes to mathematics in the NLT course, the question arises, how to equip future (mathematics) teachers so that they can help their students recognize the value of mathematics in NLT and other interdisciplinary courses.

NLT experts elaborated on the concept of interdisciplinarity by describing learning goals that state that students should have knowledge and appreciation of the different disciplines and their ways of working and thinking and how they contribute to solving a real-life problem (Eijkelhof, Boerwinkel & Krüger, 2017).

This is in accordance with Repko, Szostak and Buchberger (2017) who state that "an important step towards developing competence in interdisciplinary studies is to understand the concept of disciplinary perspective and the role of perspective taking" (p.124).

Conceptual framework

Ng and Stillman (2007) provided a framework in which the value of mathematics, mathematical confidence, and the interconnectedness of mathematics are three affective domains directly associated with interdisciplinary learning involving mathematics. In turn, they divided the domain of the value of mathematics in three categories: current relevance or usefulness of mathematics, importance of mathematics for further education and career choice, and value of mathematics in society.

In literature we see more categorizations of the value of mathematics where usefulness or current relevance of mathematics is one of the categories. Williams (2012), for instance, makes the distinction between exchange-value, enjoyment and use-value of mathematics, where the latter is viewed as a means to understand or practise competently, e.g. in engineering or science.

Ernest (2010) states that useful or necessary mathematics is primarily relevant in view of the benefit for employment and functioning in society. He declares functional numeracy or ways of thinking as being useful, but what exactly constitutes the usefulness is not made explicit. The definition of *mathematical literacy* from the PISA mathematical framework provides another perspective on what is needed to be functional in society:

> Mathematical literacy is an individual's capacity to formulate, employ, and interpret mathematics in a variety of contexts. It includes reasoning mathematically and using mathematical concepts, procedures, facts and tools to describe, explain and predict phenomena. It assists individuals to recognize the role that mathematics plays in the world and to make the well-founded judgments and decisions needed by constructive, engaged and reflective citizens. (OECD, 2016, p. 5)

The role that mathematics plays in the world brings us back to the idea of disciplinary perspective as described by Repko et al. (2017). When solving a problem requires different perspectives a mathematical perspective may well be one of them. A disciplinary perspective includes knowledge of the studied phenomena, the assumptions, the epistemology and the ways of acquiring knowledge which are characteristic to the discipline (Repko et al., 2017). To translate these ideas to secondary education we define disciplinary perspective as ways of looking at the world and ways of working and thinking that are characteristic to the field (Janssen, Hulshof & van Veen, 2018).

To specify the way mathematics looks at the world, the perspective on reality or the 'overall sense' (Repko et al., 2017), we look at the phenomena studied in mathematics. Defining mathematics as the science of patterns (Devlin, 1998), mathematics studies patterns or abstracts structures. A symbolic notation evolved to facilitate universal communication. The study of patterns requires abstracting and structuring. In addition to these two, manipulating formulas, modelling, problem solving, and reasoning are formulated as mathematical thinking activities that conjoin key concepts in the Dutch mathematics school curriculum (cTWO, 2012). These six activities belong to the disciplinary perspective shown in table 1. In NLT mathematical concepts are used, but in general no new concepts are introduced. Consequently, if we compare the mathematics curriculum with the NLT examination program, abstracting and structuring seem less relevant. Further, manipulating formulas, will be taken as part of modelling. We will elaborate on the three remaining activities.

Table 1: Description of disciplinary perspective in real-life interdisciplinary context

Ways of looking at the world	
Overall sense	Maths contributes to understanding the world (to describe, explain and predict phenomena) Maths is the study of patterns and abstract structures (with structuring, generalizing, abstracting, symbolizing) Maths uses a symbolic, formal and technical way to communicate
Ways of working and thinking	
Modelling	Modelling processes: Formulate, Employ (working mathematically), Interpret/Evaluate
Reasoning	(logical) reasoning, argumentation and proofing
Problem solving	Devising strategies, heuristics use

The motivation for creating and interpreting mathematical models in real-life situations is to mathematize a realistic situation for the purpose of answering a practical question (Gravemeijer, Stephan, Julie, Lin & Ohtani, 2017). These authors therefore argue the importance of modelling in education as something that prepares students for the digital society of the future. There are many models that describe the modelling process (Borromeo Ferri, 2006). The PISA framework (OECD, 2015) mentions three processes, namely *formulate*, *employ* and *interpret/evaluate* to capture the complexity of the modelling cycle in real-life situations. *Employ* refers to the use of mathematical concepts, facts or procedure, also known as working mathematically (Blum & Ferri, 2009). It includes applying mathematical facts, rules, algorithms, and structures when finding solutions, manipulating formulas and using mathematical tools, including technology, to help find and approximate solutions with given models.

Problem solving can play an important role in working in real-life problems when we see problem solving as the activity of using a heuristic approach (van Streun, 2001) or devising strategies as mentioned in the PISA framework. *Reasoning* is a way of thinking that can be of use in an interdisciplinary context (Eijkelhof, Boerwinkel, & Krüger, 2017). For instance, to critique arguments, to identify weaknesses and flaws in logic, to revise arguments, and to submit to peers review (Mayes & Koballa, 2012). It is a supporting process throughout the modelling process, e.g. to check a justification that is given, or provide a justification of statements or solutions to problems (OECD, 2015).

Summarizing, we describe the disciplinary perspective of mathematics in an interdisciplinary STEM course as shown in table 1. The model describes the contribution mathematics can make to interdisciplinary real-life problems, specifically in secondary education. It does not include the knowledge or ability required to use this disciplinary perspective even though we recognise mathematical confidence as an important domain in interdisciplinary mathematics education as also stated by Ng and Stillman (2007).

Data collection and analysis

To study how mathematics manifests itself in NLT (den Braber et al., 2019), data was collected through interviews, document analysis and teacher and student surveys over three years. The surveys in 2017 contained several additional questions related to the relevance or usefulness of mathematics to provide an insight in students and teachers perceptions of the value of mathematics in the sciences. For this paper we analysed student answers to one question and teacher answers to a related question, see table 2. The students were in their final year of secondary education and had studied NLT for two or three years. The teachers were NLT teachers with different disciplinary backgrounds.

Table 2: Analysed survey questions and number of answers

	Question	Type	Completed surveys
Teachers	What do you discuss with your students about the role of mathematics in the sciences?	open	84
Students	According to you, what is the importance of mathematics to the science?	open	416

We used table 1 to code the answers of students and teachers. Categories were ‘overall sense’, ‘modelling’, ‘reasoning’ and ‘problem solving’. For answers not fitting to any of the categories we used the category ‘other’. As subcategories of modelling we used ‘formulate’, ‘employ’ and ‘interpret’. The code ‘general’ was related when -part of- the answer reflected the process of modelling in general. If an answer contained more than one statement that could be in different categories the statements were coded accordingly, 445 coded student answers and 95 teacher answers. An example is shown in table 3. A single code was assigned to 389 student and 75 teacher answers.

Table 3: Example of coded student statements from one student answer

Highlighted statements	category	subcategory
The way of thinking (problem solving) and dealing with and converting numbers and formulas	Problem solving	
The way of thinking (problem-solving) and **dealing with and converting numbers and formulas**	Modelling	employ

Results

The data shows that not all answers referred to the posed questions, for both teachers and students. Instead they might express an opinion about the course, the level of mathematics or what modules were taught. These were coded as ‘other’, as were students’ statements like ‘don’t know’ or ‘don’t care’. This category was also used to code general opinions like ‘great importance’ or ‘not a lot’ and 29 students who gave general statements claiming the importance of mathematics as ‘the basis of sciences’ or other synonyms as ‘the foundation’. Also 14 teachers used general statements, using words such as ‘supportive science’ or a ‘tool’. The number of coded statements is seen in table 4.

Table 4:Number of coded statements in the categories from student and teacher answers

		Students		Teachers	
Category	subcategory	Number of statements (n=445)	Percentage of students (n=416)	Number of statements (n=95)	Percentage of teachers (n=84)
Overall sense		36	9	6	7
Modelling processes	General	4	1	4	5
	Formulate	8	2	3	4
	Employ	212	51	9	11
	Interpret/evaluate	14	3	4	5
Reasoning		14	3	0	0
Problem solving		8	2	2	2
Other		148	36	65	77

In the category ‘other’ we find 35 teacher statements, all science teachers, reflecting that they say nothing or little about the role of mathematics and there is no teacher answer mentioning reasoning or proving something. Even though we find students answers in all categories, almost half of the students reflect on the aspect of working mathematical with many statements containing the words calculate or formulas.

Inter- rater reliability with three raters was 0.79 using Fleiss Kappa.

Discussion

Rationales for interdisciplinary STEM courses are often based on the fact that the problems we face in today’s world call for perspectives and knowledge from many different areas. The possibilities for mathematics in such a course is described by Williams et al (2016) as:

> interdisciplinary mathematics education offers mathematics to the wider world in the form of added value (e.g. in problem solving), but on the other hand also offers to mathematics the added value of the wider world. (p.13)

For students, however, it is not self-evident what the added value of mathematics is. For almost one third of the students it is hard to give a description of what the relevance of mathematics is or they refer to general terms as ‘great’ or ‘mathematics is the basis of the sciences’. When they do refer to categories of disciplinary perspective it is mostly ‘working mathematically’ by doing calculations and using formulas. This is in accordance with Wolfram (2010) conclusion that not all phases of a modelling cycles are equally visible in mathematics education. We can argue that the same goes for interdisciplinary education. This might also indicate that in the current NLT course, of all disciplinary perspectives the value of the mathematical perspective is recognized the least and has a lot to gain.

We see students who say that mathematics is not very important to the sciences or student who don’t acknowledge the relevance of it. Here the role of teachers becomes even more apparent. If they don’t address perspectives it seems logical that for students this remains hidden and the benefits of perspective taking in interdisciplinary situations withheld. For teachers it requires knowledge and an attitude that might be different from what they are used to since a part of interdisciplinary perspective taking is “that when taking on other perspectives often involves temporarily setting aside your own beliefs, opinions, and attitudes” (Repko et al., 2017, p. 125). This means that the metaphors of mathematics as a servant or as the queen of other disciplines are irrelevant. The goal of disciplinary perspective is not to marginalise one discipline or to promote another but the goal is to value each discipline and use the possibilities each discipline brings to the table in a real-life situation (Braber et al, 2019).

In this paper we provided a conceptual framework for the disciplinary perspective in STEM education which can be used as a conceptual tool that may help future teachers with explicating the role or usefulness of mathematics in an interdisciplinary course.The warrants and backing in our reasoning need further elaboration. Such as reasons to include elements of the PISA framework or the statement that modelling is the most important process in the disciplinary perspective and that other processes (reasoning and problem solving) are mainly supporting the modelling process. Thereby also making a distinction between an overall sense of what mathematics is about and which processes contribute to answering an interdisciplinary question.

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