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On Science Museums, Science Capital and the Public Understanding of Mathematical Modelling

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Abstract Students' opportunities to learn informally (e.g. by watching documentaries, visiting museums) explain socio-economic inequities in school performances. To explore informal learning about mathematical modelling, I studied two science museums, as these are environments typically visited by middle-class families. I framed the study by using the notions *science capital* and the *public understanding of mathematical modelling* (PUMM) and explored how these are mediated in science museums. The research method entailed observations of displays, artefacts, and visitors. One science museum completely detached mathematics from its use-value, while the other offered histories of how people used mathematics to solve society's problems. This leads to recommendations for the design of, and research on, environments for informal learning about mathematical modelling.

Keywords Bourdieu (theory of), conceptualizing (mathematical modelling), informal learning (about mathematical modelling), parental support (for mathematical modelling), meta-knowledge (about mathematical modelling), public image (of mathematics and mathematical modelling), public understanding (of mathematics and mathematical modelling), socio-cultural environment (of mathematical modelling), science capital, science centres, science museums, theoretical perspectives (on research of mathematical modelling education), usefulness (of mathematics), use value (of mathematics), visibility (of mathematics)

1 Introduction

The Organisation for Economic Cooperation and Development (OECD) reports there are inequities that affect mathematics scores on the PISA-test (OECD 2014). The report shows that students, whose parents are higher professionals, outperform students whose parents are workers in elementary occupations. This phenomenon is observed in all participating countries in PISA. Such socio-economic inequities are caused by differences in the educational environment, as students whose parents are higher professionals are more likely to attend schools with more resources and higher qualified teachers. Yet, even if all students would learn within the same educational environment (same curriculum, same teacher, same tasks, etc.), the socio-economic background plays a role in their uptake of, and interest in, science and mathematics. Richer families can use their economic resources to create advantages, for example, by paying for tutors. Also, the social background can empower students as Archer et al. (2013) showed: within white, middle-class home environments, students are more likely to know people who work in science-related jobs and learn from them about how science works. These acquaintances can be role models in their ways of reasoning, explaining phenomena or questioning causalities. Also, in such home environments, students are more likely to be encouraged to watch documentaries or visit science museums. Thus, socio-economic inequities in science and mathematics scores are, among others, related to students' informal (out-of-school) learning opportunities.

Archer et al.'s (2013) research focused on the resources that can help less privileged students to succeed in areas of the natural sciences. Black and Hernandez-Martinez (2016) pointed out, that Archer and colleagues did not refer to mathematics and mathematical modelling. Yet, mathematics is a vital tool for solving many problems, not only in the natural sciences, but also in the social sciences, business, and so forth. Competencies in mathematical modelling assist students to succeed in non-mathematical disciplines and in future professions. Therefore, educational authorities throughout the world now advise schools and teachers to include mathematical modelling activities in their curricula (Kaiser 2014). Nevertheless, the pertinent issue of socio-economic inequity in mathematical modelling performances remains. This inequity has been observed by OECD (2014) cited at the beginning of this chapter, and which is based on parental occupations and their relation to the scores on a mathematics test, in which competencies were tested regarding the application of mathematics in real-life situations.

To explore socio-economic inequities in mathematical modelling education, I conducted a study on opportunities for students' *informal (outside-school) learning* of mathematical modelling. Informal learning comprises students' learning at home or with peers, when shopping, travelling, participating in sports, watching videos, and so forth. Informal learning is unsystematic and unstandardized (Marsick 2009); it happens ad-hoc, not guided by explicit goals or a curriculum; it is social and context-bound. Informal learning is erratic and happens in informal settings. Therefore, it is hard to capture by scientific research methods. Current research on informal learning consists of (1) studies on workplace-related learning, (2) studies through questionnaires, in which students report on their hobbies, pets and frequency of reading science magazines and having assistance with homework (e.g. Lin and Schunn, 2016), and (3) studies on *designed environments* for informal learning, such as zoos and museums (e.g. Borun et al. 1996; Van Schijndel and Raijmakers 2016). In the latter, the researchers study how visitors interact with artefacts, information, routing, each other, and what knowledge and dispositions they take home from it. In the current study, I followed this line of research and focused on the messages that visitors of science museums get about mathematical modelling. I chose to study science museums, because these are known to increase inequity between students: a visit to a (science) museum is a typical *white, middle-class* leisure activity (Archer et al. 2013). Also, when schools organize an excursion to a science museum, it means that the school is situated in an affluent country and has financial resources for the excursion.

2 Theoretical Frame

This study was framed by two concepts. The first concept is *science capital*, which is based on the sociological theory of Pierre Bourdieu. For a more detailed explanation of this theory see Vos, Hernandez-Martinez and Frejd (this volume). Here, it suffices to say that science capital is an extension of *social capital* (the social network of people who will assist when asked for help) and *cultural capital* (diplomas, knowledge of etiquette, access to information, etc.) (Bourdieu and Wacquant 1992). Both social and cultural capital are valuable resources that people own and accumulate, just like economic capital, and that can generate profits and privileges. Extending the Bourdieusian theory, Archer et al. (2013, 2015) defined science capital as the resources that offer advantages within scientific contexts, such as science dispositions, science media consumption, parental scientific knowledge, and so forth. Science capital can be accumulated in schools, but also out-of-school. A typical example of science capital that some have, and others not, is a relative who works in a science-related job and who can tell how science works. Another example of how science capital can be accumulated is through a family visit to a science museum. Archer et al. (2013, 2015) established that students with more science capital are more likely to enter professions with science components (research, engineering, etc). In the present study, I took resources pertaining to mathematics and mathematical modelling as being an integral part of science capital. This means that cognitive and meta-cognitive modelling competencies (Galbraith et al. 2007; Kaiser 2007, 2014), affect and interest (Black and Hernandez-Martinez 2016; Schukajlow et al. 2012) are included. It remains to be noted, that science capital is a conceptual construct for analytic research.

The second concept used in the present study is the *public understanding of mathematical modelling* (PUMM). PUMM is an adaptation of the *public understanding of science* (PUS), which is the understanding, awareness and engagement of the general public of scientific knowledge and organisation (Bauer, Allum and Miller 2007). Many researchers of PUS work in Institutes for Communication Studies and they study how groups of people (e.g. shoppers in a supermarket, fishers in a coastal region, readers of a certain newspaper) understand the complexities of science, technology, and innovation and how they choose to use or disregard that knowledge (e.g. Dash 2015).

PUMM is a similar construct as the *public image of mathematics,* which is the general public’s knowledge of, and about, mathematics. This public image of mathematics is shaped on the one hand by traditional mathematics education with meaningless and repetitive tasks, with alienating symbols, and so forth. On the other hand, the public image of mathematics is shaped by dialectics of modern society’s simultaneous mathematisation and de-mathematisation (Gellert and Jablonka 2007; Keitel 2006). The mathematisation of society consists of an increased use of mathematics virtually anywhere, whereby mathematics is considered as value-free and useful for establishing truths and making decisions. Simultaneously, there is a de-mathematisation process, which is the process whereby mathematics becomes increasingly invisible, being *black-boxed* in technological devices. Thus, the public image of mathematics has been studied, but PUMM has not been studied yet. There are no studies yet on whether the general public knows the term ‘mathematical modelling’ at all, or whether certain groups of people have *meta-knowledge* of mathematical modelling, which Brown and Stillman (2017) defined as “the background knowledge (…) about the nature of modelling, how it is conducted and why mathematics can be applied in real situations” (p. 357). Neither do we know, whether the general public has experienced the usefulness of mathematics through mathematical modelling activities. The current study is the first to explore PUMM, in particular PUMM among middle-class families because of its focus on science museums.

In this study, science capital and PUMM are used as complementary analytic concepts. They will be helpful in the following way. Science capital is the set of resources that enable an individual to advance in science contexts (including in mathematical modelling contexts). It is an individual person’s asset, whereby some have more of it than others. Thus, science capital is at the micro level and it is used to analyse differences between individuals. In contrast, PUMM is a social asset, used to describe a certain knowledge at the macro level, being present in the public domain. Science capital and PUMM are related, yet different. PUMM can hinder or support individuals in their accumulation of science capital. Conversely, if many people accumulate much science capital related to mathematical modelling, this will improve PUMM.

The aim of the study was to explore both science capital related to mathematical modelling and PUMM without striving for exhaustive descriptions. By focusing on the informal learning regarding mathematical modelling that can occur in science museums, I would be able to capture aspects of both. The research questions were: what possible science capital related to mathematical modelling can students (in the school going age) accumulate in science museums? What possible PUMM can science museums generate?

3 Methods

To answer the research questions, I selected the science museums/centres on the following criteria: (1) to keep cohesion in the study, the visits were to take place within a few months; (2) to have a fresh eye, I should not have visited the museums before, and (3) to limit bias, I should not have prior professional engagement with them (as consultant). This resulted in visits to the Experimentarium in Copenhagen (Denmark), and the London Science Museum (UK). On both occasions, I went together with a teacher trainer (respectively, a mathematics teacher trainer, and a primary school teacher trainer). Generally, a visit to a science museum will take more than a day, and one undertakes a spontaneous routing. To stay concentrated on the research, I limited our visits to 2 hours and to only those museum sections tagged with the keyword mathematics on the official website (the search word ‘model*’ lead to a section on wax modelling).

Similar to the research approaches of other science museum researchers (e.g. Borun, Chambers and Cleghorn 1996; Van Schijndel and Raijmakers 2016), I made field notes, photographs, and short videos. I registered the environment, the information on displays and in videos, and the activities for visitors. The visitors present during our stay were considered as a sample of convenience. Without disturbing them, I observed their activities and the time they stayed. I did not ask their permission, as the research did not breach their privacy. Additionally, I asked my colleague to read the displays, watch the videos, and engage in the activities as if it was a regular visit. Afterwards we discussed the visit and I wrote a report. I analysed these from two angles. First, I used the concept of science capital related to mathematical modelling, to identify resources, which can offer advantages to an individual in future science endeavours. Second, I used the concept of PUMM to identify messages to the general public on understanding mathematical modelling.

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4 Results

In this section, I will first report on the observations made in the Experimentarium in Copenhagen (Denmark) and then of those made in the London Science Museum (UK).

When we visited the Experimentarium in Copenhagen in June 2017, we were surprised by its brand-new architecture, design of artefacts and activities. In fact, this centre had opened only five months earlier (in January 2017). At the moment of our visit, on a Friday morning, the visitors consisted mainly of students aged 8-14 years old. Most came in a school excursion accompanied by a few teachers, which resulted in groups of 2-5 students roaming the centre unaccompanied by an adult. According to their website www.experimentarium.dk, there were two sections tagged as being about mathematics: *Bubblearium* and *The Solver* (see Fig. 1).

In the section Bubblearium, the visitors were invited to create soap bubbles, which was exciting as judged from the visitors' noise. Particularly attractive were the rings to create a cylinder around a person. However, after having made a few soap shapes, and watching others make these, all students left this section. Texts on the wall and three bubble machines (two of which were out of order) were designed with the intent to make students explore combined bubbles and the reflection in bubble surfaces. However, few students did this, and only if induced by an adult. In this section, the students' activities were haphazard and aimless, also because the shapes were not stable and disappeared after a few seconds into the air. The maximum time that visitors spent here was three minutes.

The second section in the Experimentarium tagged as mathematical was The Solver. In the middle was a labyrinth painted on the floor, on which one could walk. This labyrinth was surrounded by tables on which there were physical puzzles consisting of wooden or plastic pieces (spheres, blocks and other shapes). These were to be put together (tiled, stacked) or to be separated from one another. All objects were attractively colourful and tangible. In the time span of an hour, few visitors came to this section; it was not noisy at all. The students, who entered this section, tried one or two puzzles and left after a few unsuccessful attempts within 2 minutes. Only two boys stayed longer than half an hour, seated at one table being fully absorbed in a puzzle.

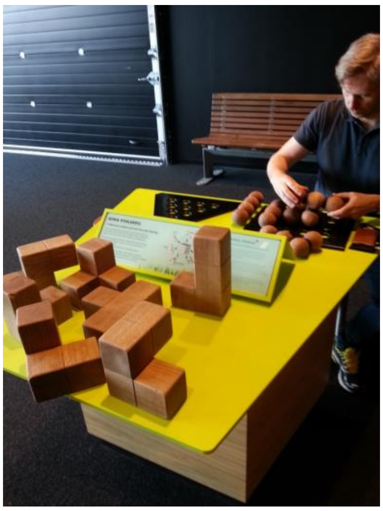

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Fig. 1 Experimentarium Copenhagen, sections *Bubblearium* (left, © Pauline Vos) and *The Solver* (right, © Pauline Vos)

Both sections in the Experimentarium in Copenhagen connected to mathematical shapes, aimed at showing that these shapes can create wonder and inquiry. When analysing in light of science capital related to mathematical modelling, in this science centre visitors can learn to enjoy mathematics. However, the exciting artefacts and activities showed a type of mathematics that has no use-value for solving problems in real-life. We, as visitors with a background in mathematics, were able to recognize the mathematics behind the puzzles and bubbles, but there were no indications that the students could. The sections neither connected to traditional mathematics education, nor to mathematical modelling. As such, the sections assisted students in accumulating a certain science capital, but no capital related to mathematical modelling. Analysing the sections in light of PUMM, we can but observe that they did not show the usefulness of mathematics and propagate a public image of mathematics as detached from real-life. By including sections tagged as mathematics, the Experimentarium clearly intends to make mathematics visible to its visitors, but its implementation keeps mathematical modelling invisible and makes PUMM void.

The second science museum visited in this study was the London Science Museum (UK). We were there on a Friday morning in May 2017. Only one section, the *Winton Gallery,* was tagged as being about mathematics according to the website (www.sciencemuseum.org.uk). It was designed by architect Zaha Hadid, who studied mathematics before turning to architecture. This section opened in December 2016. When we entered it, we were caught by violet curls hanging from the ceiling, which surrrounded an antique aircraft, described as an authentic *1929 Handley Page Gugnunc*. Displays and a video explained that the violet curls show the air flow around the aircraft in flight (see Fig. 2). It was also explained that aircraft engineers needed the Navier-Stokes equations to better understand the dangers of flying, and that mathematics is needed to make flying an aircraft safer.

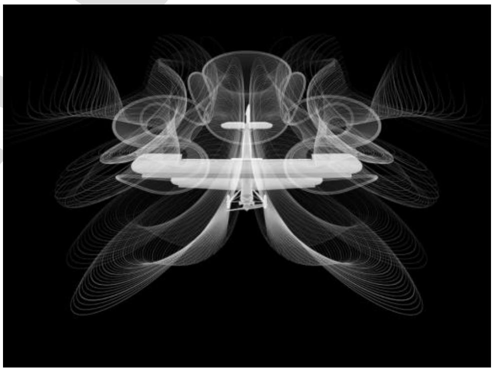

Fig. 2 Curved shapes showing airflowaround an aircraft (© Zaha Hadid Architects)

Surrounding the airplane, there were thematic exhibits telling histories of how people used mathematics for social purposes. For example, there was the story of Florence Nightingale, and how she visualized mortality statistics in the Crimean War (1853-56) to convince political and military leaders that lack of hygiene killed more soldiers than the

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enemy. Another example was the story of the flooding disaster of 1953 in England, and how Winston Churchill asked mathematicians for better weather and tide predictions. Behind glass was the authentic tide prediction machine made by Lord Kelvin, which yielded the tides a year in advance after four hours of cranking its handle. Another authentic, antique object displayed in the Winton Gallery enabled conversion of weights in international trading. It was a cabinet with 96 drawers, each holding the weights from a place overseas.

The Winton Gallery informed us, as visitors, through narrative displays, videos and artefacts in glass showcases, of which the authenticity was clarified through texts explaining their source (Vos 2015). The histories related of people who used mathematics to solve real-life problems; the terms 'model' and 'modelling' were explicitly used. Visitors were shown formulae, yet did not need to do mathematics. There was much to read, and nothing to be touched. Unlike the Experimentarium in Copenhagen, there were no tangible objects or exciting activities. During our visit, I observed only adults in the Winton Gallery and none stayed longer than 15 minutes. Although the museum attracted younger visitors, they rather went to the flight simulators elsewhere in the museum.

When looking through the lens of science capital related to mathematical modelling, the Winton Gallery offered role models of women and men who solved real-life problems by using mathematics. The term 'mathematical model' was explicitly used, the texts offered insights into the purposes of mathematical modelling. Thus, the science capital that students can accumulate here is similar to what they can gather from science documentaries related to mathematical modelling: this science capital can increase an individual's dispositions to, and knowledge about, mathematical modelling through raising curiosity and interest. However, modelling as an activity remains vague, as the visitors cannot experience modelling activities themselves. Also, the objects were untouchable and the explanations were rather verbal; both can be considered less attractive for students, whom we want to become competent modellers. Looking through the lens of PUMM, the Winton Gallery conveyed a message that mathematics is important because of its use-value. We were told histories of how women and men struggled with the creation of mathematical models to solve problems that mattered to their society. As such, this gallery can add to PUMM that mathematical modelling is a human activity and it serves social purposes, such as keeping flight passengers safe and reducing death toll in wars.

5 Conclusion, Discussion and Recommendation

The current study opened a window on informal learning of mathematical modelling, inspired by research that observed that informal learning is a source for socio-economic inequities in mathematical modelling education. Students who have access to out-of-school resources pertaining to mathematical modelling, for example through parental support, will be more likely to succeed in it. To study informal learning, I explored two science museums, because these are considered typical environments for informal learning, in particular by middle-class families (Archer et al. 2013, 2015). To frame the study, I used two concepts: (1) the concept of science capital to analyse out-of-school resources for students that can give them advantages when it comes to mathematical modelling, and (2) the public understanding of mathematical modelling (PUMM), which captures how the general public conceptualizes mathematical modelling. The research questions were: what possible science capital related to mathematical modelling can students accumulate in science museums? What possible PUMM can science museums generate?

When looking through the lens of science capital related to mathematical modelling, the study yielded a mixed picture. On the one hand, a science museum can be like the Experimentarium in Copenhagen (Denmark), and focus on offering activities on bubbles (attractive to many, but only for a short time) and puzzles (only attractive to a few) that connect to an esoteric mathematics detached from real-life. In this case, the use-value of mathematics for solving real-life problems was not aimed for and thus ignored. Such a science museum offers many experiences to the middle-class children coming there, but no science capital related to mathematical modelling. On the other hand, a science museum can be like the London Science Museum (UK), and include a section that strongly focuses on the use-value of mathematics for solving social problems. This science museum offered histories of mathematical modellers and offered insights into the purposes of mathematical modelling, thereby enhancing science capital (science dispositions and knowledge). It remains to be noted, that the science museum of the first kind offered kinaesthetic experiences and was entertaining to young students, whereas the second merely presented factual knowledge, required a lot of reading effort and did not offer appealing activities to young students. Thus, in neither of the museums, students would be able to accumulate science capital related to mathematical modelling, although in the London Museum it was accessible to visitors receptive to narratives and antique objects. This answers the first research question.

When looking through the lens of PUMM, the study yielded a different picture. We saw that a science museum like the Experimentarium can choose to offer attractive activities that people with a mathematical background will recognize as being connected to mathematics, yet which a general, non-specialized public will only experience as shapes for entertainment and detached from real-life. So, the PUMM of middle-class families will not be enhanced. On the other hand, a science museum can include a section like the Winton Gallery with a strong focus on the use-value of mathematics for solving social problems and offer meta-knowledge about mathematical modelling through personal stories and authentic artefacts. It adds to the PUMM of middle-class visitors by explicitly using the terms mathematical models and modelling, and that these serve humankind. Thus, one science museum may not add to PUMM at all, whereas another can. However, neither of the visited science museums gave visitors the opportunity to experience the usefulness of mathematics by engaging in modelling activities, and so the potential PUMM observed in this study was of the meta-knowledge type. This answers the second research question.

A number of issues arise from this study. A first issue is the difference between propagating mathematics versus propagating mathematical modelling. A science museum can focus on mathematical modelling as a human activity for solving social problems, as done in a narrative way in the Winton Gallery in the London Science Museum. In contrast, a science museum can also propagate mathematics as detached from real-life and add to the invisibility of mathematical modelling. Second, both museums contributed to the process of de-mathematisation (Gellert and Jablonka 2007) with sections on kinematics, commerce and other themes, that contained a lot of invisible mathematical modelling. Third, it remains an open question how museums intending to explicate mathematical modelling can include tangible artefacts and exciting activities, in which young visitors can actively engage.

As science museums assist students to accumulate science capital, and as they increase inequity between students, we need to consider (1) making them more accessible to less privileged students and (2) how to connect these better to mathematical modelling. To decrease inequity, it is pertinent to establish such institutions in less affluent countries, ask governments to reduce entrance fees, assist lower-class parents to understand their importance, and so forth. Also, the resources from science museums could become more universally available through digital media. As for the point to better connect science museums to mathematical modelling for students in the school-going age, we may learn from both museums in this study. The Experimentarium was more successful in offering excitement and inquiry activities, whereas the Winton Gallery was more successful in showing the usefulness of mathematics and even used the term mathematical modelling. Therefore, it is recommended to carry out further research into (1) how science museums/centres can combine excitement and inquiry activities without detaching mathematics from real-life and its use-value for solving real-life problems, (2) what other environments enhance students' informal learning about mathematical modelling (and thus their science capital), and (3) how PUMM can further be studied and enhanced.

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