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Measuring the mathematical motivation of middle and high school students

This article explores some of the current methods to measure middle and high school students' motivation for learning mathematics, reviews some of the recent literature, describes how such methods are used in a current research project, and proposes some open questions for further research.

The author acknowledges financial support from the European Union and from the European Fund for Regional Development (Interreg V Alpenrhein-Bodensee-Hochrhein).

Introduction and background

The development project "STEM becomes a habit in schools" ("MINT macht Schule") intends to improve middle and high schools students' motivation for STEM areas (science, technology, engineering, mathematics) through a large number of activities involving both schools and industrial companies in Austria and Switzerland, such as day-long trips of school classes to get an inside view and hands-on experience of tasks in the companies. See Gunesch (2017) for a background and motivation of this project, plus a more detailed description of its structure and some of its activities.

Part of the accompanying research attempts to measure students' motivation for mathematics, and improvements in the motivation caused by the activities in the project. While measuring mathematical abilities is fairly straightforward and precise (at least if enough time is available to administer thorough mathematics tests), measuring the motivation to learn mathematics and measuring students' beliefs about their mathematical abilities is not so straightforward and probably much less precise. Here we briefly review some of the methods used in the literature and discuss the method that we devised for use in our project. We attempt to gain some insight about the usefulness of the method for other projects.

Concepts: enjoyment, value, expectancy, and cost

Aiken (1974) describes two concepts which may be fundamentally useful for establishing students' motivation for mathematics: the concept of "enjoyment" and the concept of "value". Enjoyment (his "E scale") is measured by a part of the questionnaire containing 11 statements such as "mathematics is enjoyable or stimulating to me" and asking the student to indicate whether they strongly disagree / disagree / undecided / agree / strongly agree (6-level Likert scale). Value (his "V scale") is measured similarly, with 10 statements such as “mathematics has contributed greatly to science and other fields of knowledge”. The word “value” in this context is the students’ estimate of the global value of mathematics in contexts outside of their own school environment. Whether or not middle and high school students are (or even should be) able to determine such a global value may of course be debatable. Aiken’s E scale appears to be something that students can answer fairly easily since it asks them directly about their feelings involving mathematics, which they are presumably aware of and already know. His V scale, on the other hand, asks students to assess the global impact of mathematics on the entire world, which they may find difficult.

Eccles et al. (1983) introduced “expectancy-value” models into educational research. “Expectancy” and “value” are separate words, not the mathematical concept of “expected value” from probability theory. “Expectancy” is a psychological concept that measures students’ belief that they will be successful in mathematics classes. “Value” measures students’ believed importance of the task, like Aiken’s V scale. Eccles also introduced the concept of (psychological) “cost” (Eccles & Wigfield, 1995; see also Barron & Hulleman, 2015) and hypothesized three dimensions of cost: “perceived effort” (how difficult it is to be successful), “loss of valued alternatives” (the assumption that engaging in one activity restricts the time available for other activities), and “psychological cost of failure” (anxiety). Flake et al. (2015) suggest distinguishing between “task effort” and “outside effort”.

Kosovich et al. (2014) used a brief 10-item scale to measure school students’ expectancy, value, and cost for their math and science classes (3 items for expectancy, such as “I know I can learn the material in my math class”, 3 items for value – similar to Aiken’s but shorter, such as “I value my math class”, and 4 items for cost, such as “my math classwork requires too much time”. (This item will be discussed in more detail later in this article.) Kosovich’s scale is convenient to use because it is short.

PISA questions and their justification; actual activities in mathematics

The PISA studies (OECD, 2012) have the advantage of being based on a very large number of students and of also measuring actual mathematics abilities of school students to refine their questionnaires. Thus, despite the considerable public debate about the PISA studies, they are a very useful source of instruments. One such instrument is the scale “general interest in mathematics”, where students indicate their agreement to statements such as “I am interested in the things we learn in mathematics class”; this is similar to Aiken’s E scale. Another, presumably more direct, instrument (also from PISA) for measuring students’ mathematical motivation asks how much time they spend on activities involving mathematics. Statements include "I help my friends in mathematics" and "I spend more than two hours per day outside of school doing mathematics".

Open questions and future research

The following questions are (in the author's opinion) not yet satisfactorily answered in the literature, and further work is needed.

Are expectancy-value-cost models more useful than enjoyment-value models to measure mathematical attitudes, predict future mathematics performance, and predict career choices in STEM areas? Recent literature seems to focus on expectancy-value-cost models, somewhat ignoring enjoyment. Yet enjoyment of mathematics may be a (more) crucial concept to predict students' future mathematics performance and related career choices.

How do the results of psychological models (EV, EVC) relate to results of mathematical aptitude tests (which make students solve actual mathematical problems instead of asking about their perception of mathematics)?

Assuming PISA questions are the golden standard, how "good" are the EV and EVC models? This will be evaluated in detail during this project.

The PISA activity items include "I am involved in mathematical competitions", "I participate in activities of a mathematics club", "I play chess", and "I program computers". Are chess and computer programming really mathematics? (Either way, computer programming is highly relevant in this STEM project.) And is it meaningful to use a Likert scale to ask about activity in a mathematics club (which may not exist in the area) and competitions (which may not involve the majority of students at all)?

The "cost" component (of EVC) contains items containing phrases like "I spend too much time doing mathematics". The author wonders if the item and the way that it is phrased is really meaningful in the following way: We would clearly assume that each item is such that its numerical outcome (in the case of a 6-level Likert scale, the outcome is a number in the set $\{1,2,...,6\}$) is a monotonic function of the property which the item is supposed to measure (e.g., motivation to learn mathematics). We would clearly not want an item where students who have a very high value (of motivation) will likely choose 6 and at the same time students who have a very low value will also likely choose 6. But this could happen if the aforementioned function is first decreasing in the left half of the interval and then increasing in the right half. This may not be purely abstract speculation: It is reasonable to expect that students who dislike mathematics will choose a high value for their answer to the question "I spend too much time doing mathematics”. But maybe so would students who enjoy mathematics so much that they spend a huge amount of time on it and enjoy it, but who would nonetheless feel that it is “too much time” because as a direct consequence there is little time left for other activities.

The relationship between students’ mathematical abilities and their belief in their mathematical abilities is not obvious. There is some indication that belief in the own abilities (attitude) is a particularly good predictor for future achievement, with the influence as strong as that of the IQ (Chen et al., 2018). On the other hand, students’ beliefs about their own abilities may not accurately reflect their current abilities: university examinations often reveal that some students have great confidence in their abilities despite having actually very little knowledge, whereas others display total lack of confidence yet answer all exam questions perfectly.

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