Mathematical Theories of Creativity in Contemporary Research: A Literature Review

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Abstract **- The paper at hand presents a systematic analysis of theoretical backgrounds in articles about mathematical creativity over the period of 2007 – 2019. Due to the multifaceted concept of creativity, various keywords were used for the literature study. Those keywords were identified in a search in relevant literature and ten years of PME proceedings. The coding of the articles as well as the inductively created category system is presented. As a result, we see that most authors refer to a multitude of de-scriptions to examine creativity. With this approach we were able to shed light to the characteristics of conceptualizations of creativity which are discussed.**

INTRODUCTION

Creativity – also among students – is increasingly being explored – since it is also seen as a central component of modern technology in society (Leikin & Pitta-Pantazi, 2013). There are very different views about what creativity is and, accordingly, different approaches how creativity is examined – and different trends become apparent. We therefore see the need to get a clearer and systematic picture of the theoretical basis on which current research in this field is based. For this purpose, we conducted a configurative literature study (similar to Nilsson, Schindler, & Bakker, 2018) (see Gough, Oliver, & Thomas, 2013), where – in a first step – we systematically searched for adequate keywords in the proceedings of ten years of PME and – in a second step – developed a categorization system for the analysis of the articles. One result is that seven other words for the term creativity are used synonymously. In addition, the analysis shows that only one third of the considered articles define creativity, and the majority of articles indicate many different descriptions of creativity.

BACKGROUND

Mathematical creativity as a research topic is gaining increasing interest in recent years (cf. Singer, Sheffield, & Leikin, 2017). For example, a PsychINFO® keyword search for "math" "creativ*", "innovat*" and similar expressions (see below for more details) reveals a doubling of the number of articles related to the topic in the last 10. For this interest in creativity and its importance, there are many reasons. To name a few, creativity is considered to be important in problem solving, making innovations, and being a responsible citizen (Kim, Roh, & Cho, 2016). Barak summarizes: "It is evident that creative thinking skills, openness to change, flexibility, and the ability to cope with challenging tasks are essential for integration in today's society and workplace, whereas specific skills and knowledge are rapidly becoming obsolete and new fields are emerging every few years." (Barak, 2009, p. 345) However, there is no single, universally accepted definition for creativity (Treffinger et al., 2002). The definitions that are used are often vague like "[creativity can be defined] as the process of producing something that is both original and worthwhile" (Sternberg & Sternberg, 2011, p. 479). For research, however, it is important to have well-defined terms and concepts (Rhodes, 1961). Therefore, vague concepts need to be discussed and sharpened. This is especially true for research on subject-specific creativity, and it is appropriate to conduct a thorough review to record which definitions and theories are used in research on mathematical creativity. In this article, the preparation and implementation of a configurative literature study is presented. The first part deals with the selection of keywords to conduct the review. The second part presents the results of a descriptive analysis of our review.

RESEARCH QUESTIONS

It is of interest to find out how elements such as theories, models or – more generally– conceptualizations on the subject of mathematical creativity are used in contemporary research. This raises the following research questions: 1. Which words are used synonymously for creativity and thus result in a keyword for a configurative literature search? 2. How is creativity in contemporary research conceptualized?

METHODOLOGY

In order to analyze the theories, models, and other elements which are mentioned in the theoretical parts of papers about mathematical creativity, we conducted a configurative literature study, similar to Nilsson et al. (2018) who based their research on Gough et al. (2013). For our purpose, we adopted this approach because we not only wanted to extract theories but also include smaller remarks, which do not have the claim of a theory. Searching for keywords and articles There is no accepted definition of creativity and there are many different conceptualizations of the term (Treffinger, Young, Selby, & Shepardson, 2002). Therefore, it is important to be aware that there might be other signal words than "creativ*", which describe/conceptualize creativity. To create a list of appropriate search terms aiming at combined with Figure 1: Number of articles found in the database PsycINFO® with the keywords math* and creativity-related keywords. In total, 723 articles were found finding articles for review, a systematic screening of conference and handbook articles was conducted. For this screening, all PME proceedings from 2007 to 2016 were included as well as several handbooks like Encyclopedia of creativity, invention, innovation and entrepreneurship edited by Carayannis (2013), Sternberg's (1999) Handbook of creativity, or handbooks that are specific for mathematics education, e.g. Gutiérrez, Leder, and Boero's (2016) The second handbook of research on the psychology of mathematics education. In these proceedings and handbooks, all articles with "creativ*" in their title were browsed for their keywords to find expressions that are used synonymously for creativity. For our list (see results Section), we omitted terms that describe components of creativity; for example. Lerman (2014) described mathematical creativity as a combination of fluency, flexibility, originality, and elaboration. These words were not included in the list of keywords, because these words are too everyday-linguistic and not do not have sufficient specificity. To search for articles, PsycINFO® has been chosen as a database which is one of the most frequently used databases for behavioral and science research (American Psychological Association, 2017). As this database covers many different journals from different fields, we combined our keywords with math*. As another restriction, only those articles are included which are published in a journal listed in the Web of Science (WoS) (with a focus on "education & educational research", "education, scientific disciplines", and "education, special"). This decision was made as an objective criterion to ensure a certain quality of the articles. However, this prerequisite to use only journals listed in the WoS leads to the exclusion of some journals that are relevant to mathematics education, like ZDM – Mathematics Education (see Discussion). We have decided to search within the last ten years for appropriate articles. To make sure not to miss any articles because of infrequently updated databases, we chose the ten-year period from 2007 to 2016. Screening the articles: focus on titles, abstracts, and keywords (criteria for inclusion of articles) Only articles with creativity as a central topic (compared to, e.g., "creative methods to draw graphs") should be included in the review. Therefore, titles, abstracts, and keywords were scanned. Articles that could not be clearly included or excluded were discussed in an expert discussion and included in the case of doubt. Coding the Articles: Analysis of the theoretical parts For the remaining articles, we focused on theoretical parts similar to Nilsson et al. (2018). If no theoretical part was labelled in an article, everything up to the research question(s) and methods was analyzed. This step is the last to exclude articles, which did not focus on creativity. To compare the conceptualizations of creativity and the ways in which theories or other concepts on creativity are used in the selected articles, inductive categories were developed through a qualitative content analysis (see Mayring, 2015, for details). better readability, we call a phrase with a reference to literature a "statement" which built the analysis unit for our research. In consequence, if there was a phrase which did not have any reference to other literature, it was not referred to be a statement. We clustered the statements from each article and then built categories according to the emerging clusters.

RESULTS Extraction of keywords and articles The extraction of keywords that are used synonymously to creativity was done for two different data types: more than 10 different handbooks from the fields of creativity and mathematics education and the PME proceedings from 2007 to 2016. For the handbooks, we were able to extract a list of four central keywords (Table 1; first column). When searching for keywords in the PME proceedings, we found eight keywords (Table 1; second column) which are representative in several contributions. We see that there is an overlap in both of the data types and that the list extracted from the handbooks is completely included in the list emerged from the PME proceedings. The latter seem to give a more varied picture of possible synonyms of or concepts related to creativity. For the search in PsycINFO®, all eight keywords are used. Figure 2 summarizes the steps within the search procedure and the number of articles that were found and that remained after each step. Initially, 723 articles that fit the search terms were found in the database. After the alignment with the list of journals in the WoS, 182 articles were selected. The titles, abstracts, and keywords of these articles were scanned, resulting in a selection of 26 articles of which the theoretical part was read (see methodology section). Of those 26 articles, however, only 15 articles were on topic and reviewed. Thus, in total, 8 % (15 of 182) of the articles using keywords from our list and being published in journals that are listed in the WoS actually dealt with research on creativity and were included in the further analysis. Table 2 shows the numbers of articles sorted by the journals in which they have been published. Thinking Skills and Creativity is most often represented – half of the articles were published here. Coding the articles: Analysis of the theoretical parts Seven different categories of references arose inductively from the statements in the articles: (1) Definition: Statements, which are clearly labeled with an expression like “defined as”. (2) Components: Statements, which provide a closed list of properties to describe creativity. (3) Description: Statements, which describe creativity but do not refer to a closed list (as components). (4) Development: Statements, which hint either at special programs or trainings to foster creativity; or statements, which describe developments of creativity in e.g. students. (5) Integration: Statements, which show that the mentioned aspect is seen as an aspect of a bigger construct (e.g., giftedness). (6) Relation: Statements, which show a link to another construct and are not an integration (e.g., achievement). (7) Assessment: Statements, which deal with the assessment of creativity. Table 3 shows the numbers of articles, which include at least one statement indicating each category. Definition. It is striking that in only four articles, statements referring to definition were found. For example, Daugherty and White (2008) refer to Torrance and write: “Torrance (1965, 1988) defined creativity as sensing gaps in information, formulating solutions that complete the information, testing these solutions, and communicating the results” (p. 31). Ayas and Sak (2014) commit the statement: “creativity usually is defined as the ability to generate ideas or products that are novel and useful (Boden, 2004; Cropley, 1999; Mayer, 1999; Piffer, 2012; Plucker, Beghetto, & Dow, 2004; Sak, 2004; Sternberg & Lubart,1995)” (p. 195) and refer thereby to more authors. We see – also with the inclusion of the other two statements which refer to the category definition – that the authors show different emphasis: The spectrum ranges from a feeling (Daugherty & White, 2008) to specific abilities (Ayas & Sak, 2014) to the properties of products (Ayas & Sak, 2014; Barak, 2009; Kim et al., 2016). When analyzing categories description and components, we see (Table 4) that the majority of the articles presents at least four statements assigning to these categories. To get a more detailed insight, we will now focus on one particular article which presents a broad variety of statements: Ayas and Sak's (2014) “Objective measure of scientific creativity”. In addition to the above stated definition, the authors also provide statements assigned to the categories components or description. With the following quote Ayas and Sak compose scientific creativity as a process of three stages “These three processes [referring to Scientific Discovery as Dual Search; SDDS] guide the entire process of scientific creativity from formulation of hypotheses, through experimental evaluations to decisions to accept or reject hypotheses” (ibid., p. 197). Additionally, the authors describe a variety of aspects of creativity and cover different scopes of application. They refer, for example, to the domain-specificity of creativity: “The evidence for domain specificity of creativity is found both in broadly defined cognitive domains (e.g., mathematical, linguistic, and musical) and in narrowly defined tasks or content domains (e.g., poetry writing,

story writing, and collage making) (Baer, 1998)" (ibid., p. 196). In other parts, further statements are presented, partly with contrary conclusions. The focus in the authors' study is a computer based Assessment of Creativity, which is why many assessment statements are made. In total, Ayas and Sak (2014) cover all categories. Overall, this shows which categories are covered in a theoretical part of an article and whether assumptions are based on definitions or rather on descriptions. It is also possible to reconstruct the extent to which research is conducted either within creativity or whether the focus is on linking to other constructs, such as SDDS and computer-based assessment and how these elements are characterized.

DISCUSSION AND OUTLOOK

The aim of this article was to analyze how creativity is described and conceptualized in contemporary research. A two-step procedure was conducted: In the first step, the review was preceded by systematically searching for synonyms of creativity. This step was necessary because there is no uniform definition for the subject area and, therefore, a large number of views and descriptions exist in parallel. We found eight keywords which were used for the research: creativ*, divergent think*, innovat*, illuminat*, invent*, aha*, bisociat*, and overcom* fixation. These words are seen as central to creativity in the considered sources and are often used synonymously. The lack of a clear definition (Singer et al., 2017) and a high number of definitions (Treffinger et al., 2002) is espoused by other researchers as well. After the hit list was filtered, only about 8% (26 out of 182) of the total articles remained for analysis. This was due to the fact that some keywords appear in other contexts (e.g., "the paper illuminates the research)

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