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INVESTIGATION OF PRE-SERVICE TEACHERS' MATHEMATICAL CONNECTION SKILLS THROUGH CONCEPT MAPS

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ABSTRACT

Education faculties need to be attentive to studies in mathematical connection skills, as it is one of the most important components of mathematics education and mathematical power. In this context, this study aims to reveal the relationship between the basic concepts presented in the Introduction to Algebra course of the Elementary Mathematics Teaching Program, through concept maps. The study is a qualitative research design, conducted with the case study method used to examine the situations of one or more participants in an event, training or activity in detail. Sixty-one elementary mathematics teacher candidates participated in the research. During the course, the concepts are first presented with definitions and examples, then each concept is compared with the previous ones and the differences and similarities are discussed. At the end of the course, the meaning of the newly learned concept is worked out by relating it to the previous concepts. The course was fourteen weeks. Initially, concept maps were reviewed with the pre-service teachers along with examples and features related to creating concept maps. At the end of the course, the participants were asked to create a concept map about the specific algebraic structures encountered during the term. The main data collection tool of the study is the concept maps. However, semi-structured interviews were conducted with a group of prospective teachers to provide triangulation, ensuring reliability in qualitative studies. The personal observations of the researcher were included in the findings. Data obtained during the study were analysed by descriptive method as well as a four-valued analysis method to facilitate the grouping of mathematical association levels and to provide quantitative data support. The excerpts from the interview records were presented with the concept map created by the relevant teacher candidates, illustrating in more detail the structure of the mathematical association. The study determined that most of the pre-service mathematics teachers were able to make ‘moderate’ connections. Learning environments that emphasize the hierarchical and related structure of mathematical concepts positively affect the development of mathematical connection skills.

Keywords: Teacher candidate, mathematical connection, algebraic concepts, concept map.

INTRODUCTION

In today's science world, where change and innovation are based, mathematics continues to occupy a very critical place in relation to other disciplines. This perception stems from strong conceptual relationships within mathematics as well as its crucial position in every aspect of life. Despite this crucial position, mathematics is considered by students as a field of interest consisting of abstract guidelines and principles that are independent of each other and far from daily life, and equations and formulas that should be learned individually. Students also see mathematics as an interest that is only useful for exams. In order to overcome this idea, students need to understand mathematics' connection within its discipline, with other disciplines and daily life (Baki & Şahin, 2004; Şahin, 2007).

Mathematics is a field of science where the prerequisite principle is strong. For this reason, it is fundamental for individuals to connect newly learned concepts with previously learned ones in order to achieve permanent and meaningful learning. The standards of the National Council of Mathematics Teachers (NCTM), which is an important reference for studies on math education, and the math teaching program of the Ministry of National Education (MoNE) emphasize the following: building a connection between learned concepts and processes, multi-representation of mathematical concepts and rules for transforming these multi-representations into each other and the relationships between them, and connecting different math concepts with each other. In summary, mathematical connection skills should be developed for individuals to have an improved mathematical power (NCTM, 2000; MEB, 2018).

Studies on the investigation and classification of mathematical connections adopt different approaches. However, many studies were found that focused on three basic connection types; mathematics' connection with daily life, connection with other disciplines, and connection within the discipline, and the conceptual framework of these three basic connection types (NCTM, 2000; Brooks & Brooks, 2001; Bingölbali & Coşkun, 2016; Fauzi, 2015; Siregar & Surya, 2017; Hendriana, Sulamet & Sumarmo, 2014; Rohendi & Dulpaja; 2013; Chapman, 2012; Yavuz Mumcu, 2018; Özgen, 2013). Conversely, this study considered mathematical connection as the connection of mathematical terms with each other; namely, the mathematical connection within the discipline.

Concept maps are one of the most common methods used to determine the connection between concepts. Based on Ausubel's theory of Meaningful Learning, Novak and Gowin (1984) developed concept maps. Concept maps can be designed as graphs connecting concepts related to each other building a chain of connections. This can identify students' cognitive structure and reveal students' current knowledge for both the student and teacher (Baki & Şahin, 2004; Özdemir, 2005).

The development of mathematical connection skills in students is closely related to the teachers' awareness of connection and requires them to equip with an improved connection skill (Baroody & Coslick, 1998).

Mathematical connection skill, an important component of mathematics education and mathematical power, should be carefully discoursed in educational faculties for teachers. Several theories and methods introduced in courses can look to the functional structure of school mathematics only if preservice teachers are aware of the relationship between mathematical terms. For this reason, there is importance in stressing the relationship between mathematical terms in the content of "field courses" of the teacher education programs. This study aims to reveal how preservice teachers construct the relationship between the concepts presented in the Introduction to Algebra course of the Elementary Mathematics Teaching Program through concept maps.

Within this conceptual framework, the relationship between concepts in concept maps created by preservice teachers are evaluated according to not only the representations regarding the connection of a concept to a previous one, but also the interrelationship of concepts possessing common properties (Yavuz Mumcu, 2018). Therefore, how preservice teachers construct the relationship between the concepts of "ring (and special rings, with identity, commutative, and commutative-identity, with division), integral domain, field, and ideal" –which are all included in the content of the Introduction to Algebra course and can be indicated as special algebraic structures among fundamental concepts– in their minds and at which level they can illustrate this through a concept map constitutes the main focus of the study.

METHOD

This was a qualitative study. The method of case study, where a case, education implemented, or the cases of one or several participants are examined in detail, was used in the study. This method was thought to be appropriate for the study because the researcher was in a teaching position at the same time (Merriam, 1998; Çepni, 2009; Creswell, 2009; Yıldırım & Şimşek, 2013). The study aimed to investigate preservice elementary mathematics teachers' skills in connecting the concepts included in the Introduction to Algebra course and their level of illustrating these connections in a concept map. Sixty-one junior preservice elementary mathematics teachers from a public university in the Central Anatolia Region of Turkey constituted the participants of the study. These participants were selected using the convenient sampling technique (Büyüköztürk, 2009). In the teaching process of the researcher, the concepts were presented together with their definitions and related examples, the similarities and differences of each concept was discussed with a comparison with the previous concept, and negotiation practices on how the newly learned concept is related to the previous concepts were given at the end of the lesson. The implementation process lasted 14 weeks. At the beginning of this course, the characteristics of concept maps and examples of the ways to create concept maps were again reviewed with the preservice teachers. At the end of the process (14th week), the question "Please create a concept map explaining the relationship between ring (and special rings) –a fundamental algebraic structure–, integral domain, field, and ideal." was posed to the participants. Then they were asked to present their opinions on the algebraic structures and the relationship between these structures they observed throughout the process. The basic data collection tool of the study was the concept maps created by the preservice teachers at the end of the term. However, in order to provide triangulation, a method ensuring reliability in qualitative studies, a semi-structured interview was carried out with a group of randomly selected preservice teachers. The personal observations of the researcher were also presented in the results.

The study results were analyzed using descriptive methods. Data obtained with this method were summarized and interpreted according to the previously determined themes (Yıldırım & Şimşek, 2013). This analysis was used in this study so that data obtained was organized and interpreted with a descriptive approach and presented in a way representing the existing situation. Data obtained from the concept maps were first described systematically and clearly. In this type of analysis, four phases form a framework, data is processed according to the thematic framework, results are identified, and results interpreted (Yıldırım & Şimşek, 2013). The same process was followed in the study. In addition to this, an analysis method with four characteristics which facilitates grouping the mathematical connection levels in the evaluation and provides further qualitative data, as pointed by Novak and Gowin (1984), was used. The four fundamental characteristics considered in the analysis are as follows: the presence of all concepts (and definitions) expected to be included in the concept map (Concepts), the presence of accurate directions of connections between concepts (Hierarchies), the presence of multiple connections (Cross Connections), and the presence of examples related to the concept if any (Examples). Based on these fundamental characteristics, a grading system and evaluation method were determined for the concept maps created. In this method, for each concept given with its definition and for each related connection one point was given, for each extra connection (including examples) three points, for each hierarchical level five points, and for each cross connection ten points were given (Şahin, 2002). In this systematic examination, the concept maps were evaluated by three experts, one is the researcher and the other two are field experts. A decision was made on the differences observed in grading. The participants' scores on each characteristic were presented in percentage and frequency tables. With the grouping made on the overall scores obtained, the preservice teachers exhibiting "low, mid, and high" -level mathematical connection skills were determined. Semi-structured interviews were carried out with three preservice teachers randomly selected from each group. The aim was to obtain justification for the connections put forward by the preservice teachers.

FINDINGS (RESULTS)

At the end of the data analysis process, the concept maps were evaluated and grouped according to the determined criteria. The related results were presented along with the data obtained from the semi-structured interviews made by three preservice teachers randomly selected from each group.

Results Obtained from the Concept Maps

During the data analysis, it was determined that two preservice teachers (3%) did not create any drawing. During the implementation process these preservice teachers were observed as not having sufficient interest in the course, experienced some difficulties in understanding the course, and did not regularly attend the course due to their schedule of courses they failed in the previous terms. For this reason, the concept maps of 59 preservice teachers were included in the analysis and percent and frequency values were calculated accordingly.

Table 1. Concept Maps Coding Table (Preservice teachers with codes PT 55 and PT 59 were excluded from the analysis since they did not create a concept map.)

Groups	Preservice Teachers PTi (i=1-61)	Concepts (x1 score)	n	%	Extra Connection (x3 score)	n	%	Hierarchies (x5 score)	n	%	Cross Connections (x10 score)	n	%	Total score	n	%
Low N=9	PT (6, 10, 11, 18, 19, 24, 31, 36, 41)	6-7	8	14	0	6	10	5	2	0.3	0	9	15	11-12	7	12
		8	1	0.1	0-3	3	0.5	10-15	7	12	-	-	-	13-26	2	0.3
Mid N=32	PT (1, 3, 12, 13, 14, 15, 16, 17, 21, 22, 25, 26, 27, 28, 32, 33, 37, 38, 40, 42, 43, 44, 48, 49, 50, 51, 52, 54, 56, 57,58, 60)	7	4	0.6	0	17	29	15	24	41	10	27	46	32	22	37
		8	28	47	3	15	25	20	8	14	10	5	0.8	33-41	10	17
High N=18	PT (2, 4, 5, 7, 8, 9, 20, 23, 29, 30, 34, 35, 39, 45, 46, 47, 53, 61)	-	-	-	3-6	12	20	20	13	22	20	11	19	43-46	12	20
		8	18	30	6	6	10	20-25	5	0.8	20	7	12	46-50	6	10

The groupings made according to the total scores shown in Table 1, examples selected from the concept maps the preservice teachers created, and excerpts from the semi-structured interview transcriptions resulting in the mathematical connection skills are presented below in detail.

Group Exhibiting Low-Level Mathematical Connection

There were nine (15%) preservice teachers in this group. The concept maps created by these participants were partially correct but had some deficiencies. The participants only wrote the name of the concepts they were asked to connect and did not include any information on the connection arrows. They were able to identify the definitions of these concepts but failed to state justifications in their interpretation on the relationship between them.

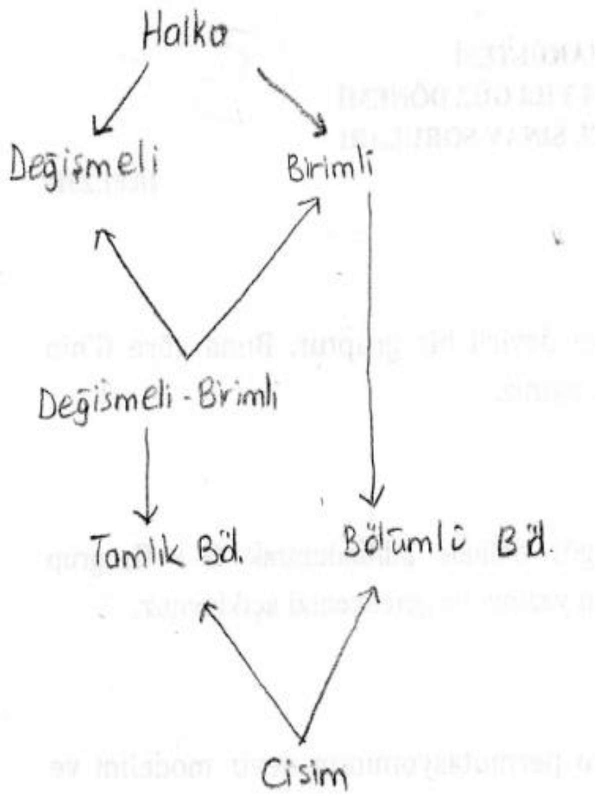

Figure 1. Example Concept Map With a Low Score Belonging to PT19 .

Figure 1 shows the concept map of the preservice teacher with the code PT19. In the map, only seven of the concepts were included, the concept "Ideal" was not mentioned, and an expression related to a definition, extra connection, example, or relationships was not included. In the map, a connection or hierarchies was not included according to a single concept but two steps of an hierarchy-one from "ring" to "commutative" and "identity"; one from field to other two concepts-is expressed. It was also determined that two different branches, one starting from the concept "Ring" and the other starting from the concept "Field", were observed, and that ring with identity was expressed as a ring with division. As a result, the grading of the concept map for the preservice teacher (code PT19) is summarized as follows:

Concepts: 7x1=7
Extra Connection: 0x3= 0
Hierarchies: 2x5=10
Cross connections: 0x10=0
Total 17 points

While grading the fundamental characteristics considered during the evaluation, the participant was given seven points in the concepts section since seven concepts out of eight concepts were included; zero points in the extra connection section since no extra connection was given; ten points in the hierarchy's section since there was no hierarchical ordering in one direction and there was one ordering for each of the two directions; and zero points in the cross connections since no cross connection was built. Therefore, the participant had a total score of 17.

A semi-structured interview was made with the preservice teacher (code PT19) in order to reveal which characteristics this concept map, where no explanation was given, indicates in terms of mathematical connection. An excerpt from the interview transcription is stated below.

Excerpt from the Interview Transcript of the Preservice Teacher (Code PT19)

R: Could you please explain the concept map you created briefly?

PT19: The concepts you gave were ring, special rings, field, integral domain, and ideal. I placed them in order. There are two types of rings; commutative ring and ring with identity; if these two exist together, it becomes a commutative-identity ring. In fact, if both commutative and identity element are present, we call it as an integral domain too, don't we? (waits for confirmation, the researcher is silent). If it is a ring with identity, we also have zero divisor; for this reason, too, it is a ring with division, here, I wrote mistakenly an abbreviation like it is a division domain, probably, I also was confused with this while writing integral domain (laughs). When it comes to "Field", we, in fact, discussed a theorem that each field is an integral domain in the classroom, a ring with division also seems to have the same characteristic, then we can say that field, at the same time, is a ring with division. Only, I could not figure out where to place ideal, I guess I did not completely understand the characteristics of it.

R: Do you know the definitions and properties of these concepts?

PT19: While solving questions or when asked whether an algebraic structure is a ring, or field, or integral domain, I can somehow solve it step by step. However, I can never state them by memory.

R: What kind of plan were you making when you placed the algebraic structures in the concept map?

PT19: Actually, the ring was given first, then since it says special rings, there are rings with identity, commutative, commutative-identity, and rings with division. First, I looked at these.

R: What kind of relationship do you think there is between these structures?

PT19: In fact, I think there are three types of rings: with identity, commutative, and with division, because there are properties. However, if the ring is commutative and has an identity element too, it is also called commutative-identity, which makes it like there are four types.

R: How about other concepts included in the figure?

PT19: Integral domain and field, you already gave them to us.

R: Is there a similar relationship between field, integral domain, and ring with division? You put a connection arrow to both.

PT19: Yes, field is, in fact, both integral domain and ring with division, because all possess the same characteristic.

R: In this case, can it be also proposed that each integral domain is a field or ring with division?

PT19: We can ring with division, but I guess each integral domain is not a field, because in the course we said each field is an integral domain but not the other way around, I remember like this, I am confused now.

R: In the figure you created, there are two different directions starting from both ring and field, which concept you addressed as the starting concept?

PT19: In fact, ring is the fundamental concept but since the field is related to it, we can consider it as a separate start, too.

R: If you designed this concept map again, would there be any part you want to reconfigure?

PT19: No, there is nothing inaccurate here, maybe it can be better understood if we put the ring at the center and design the map as a network.

Group Exhibiting Mid-Level Mathematical Connection

There were 32 (54%) preservice teachers in this group. The concept maps created by these preservice teachers generally included the correct definitions of the concepts although a few (n=3) had deficiencies regarding the concept. The connections between concepts were expressed in an accurate way and sufficient explanations, to a large extent, were given on the connection arrows. Additionally, cross connections were given in one section but there were some deficiencies regarding stating examples.

Figure 2. Example Concept Map in the Mid-Level Group Belonging to PT37.

Figure 2 shows the concept map of the preservice teacher (code PT37), the ideal concept was seen to have some deficiencies. The preservice teacher attempted to state the definitions of other concepts using a mathematical language and symbols as far as possible, and also stated an example regarding "zero divisor" on the connection arrow from "field" to "integral domain". As a result, the grading of the concept map for the preservice teacher (code PT37) is summarized as follows:

Concepts:	7x1=7
Extra connection:	0x3= 0
Hierarchies:	3x5=15
Cross connections:	1x10=10
Total	32 points

Some preservice teachers in the mid-level group of mathematical connection perspective ignored one of the concepts, as it was in the case PT37. Therefore, they carried out incomplete staggering also in the hierarchical grouping. However, some participants in the same group were encountered including all the concepts in their concept map and were therefore able to move one step further in the hierarchical grouping. However, no preservice teacher was found in this group who can build more than one extra connection. The concept map of preservice teacher (coded PT52) exhibiting a mid-level mathematical connection is depicted below. To further explain, the excerpts from this second preservice teacher are presented.

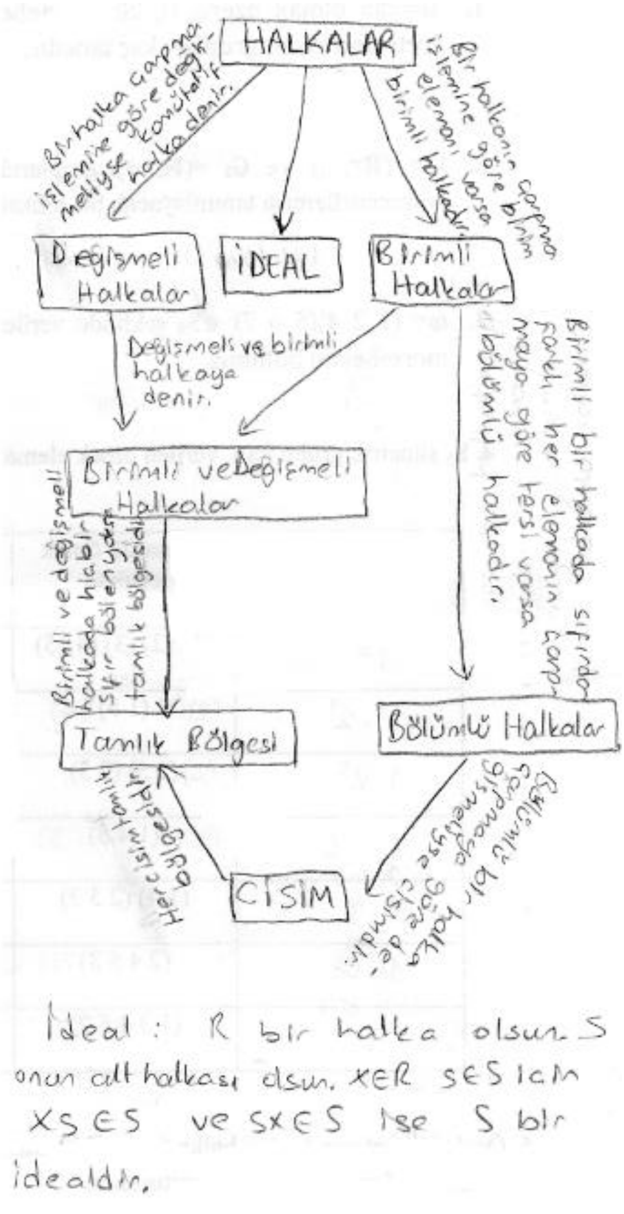

Figure 3. Example Concept Map in the Mid-Level Group Belonging to PT52.

Figure 3 shows the concept map of the preservice teacher (code PT52). This map included all of the concepts and considered "ring" as the fundamental concept. In the concept map, characteristics other concepts need to possess to be a ring were accurately positioned on the arrows and ordered with correct hierarchical connections and extra connections. In the last part of the concept map, the one-way relationship between "field" and "integral domain" was accurately expressed. The concept "ideal", on the other hand, was only related to "ring" and the definition of this concept was separately included outside the map. As a result, the grading of the preservice teacher (code PT52) regarding the concept map can be summarized as follows:

Concepts:	8x1=8
Extra Connection:	0x3= 0
Hierarchies:	4x5=20
Cross Connections:	1x10=10
Total	38 points

Excerpt from the Interview Transcript of the Preservice Teacher (code PT52)

R: Could you please explain the concept map you created briefly?

PT52: What we were asked is to create a concept map covering ring and all related rings, field, integral domain, and ideal. I wrote all of them with respect to their properties.

R: Do you know the definitions and properties of these concepts?

PT52: Of course, in fact, I could write it with the set-operation-element properties; but, I wrote their relationship in short there. I only had to write ideal in a clear way because it is only related to ring, I just noted it at last since it does not have properties like commutative, with identity, or zero divisor.

R: What kind of plan were you making when you placed the algebraic structures in the concept map?

PT52: I put the one with the most fundamental property at top, ring is like something which produces all of them. Then, from this, I put arrows to other rings with explanations onto them, integral domain and field possess most of the properties, I put them at last.

R: What kind of relationship do you think there is between these structures?

PT52: I think there is a multi-staged relationship, if you add a property to one of them, it becomes another thing, but all of them start from the ring.

R: What kind of relationship is there between field, integral domain, and ring with division? From your explanation here, what kind of hierarchical ordering should we think of?

PT52: If a ring with division is commutative according to the second operation, then it is a field, every field is an integral domain, we know how to prove it.

R: In this case, can it be also proposed that each integral domain is a field or ring with division?

PT52: No, each field is an integral domain at the same time but not the other way around. However, is an integral domain ring with division at the same time, let me think for a minute… (looking at the concept map), in fact, integral domain is a ring with identity and commutative ring; also, it does not zero divisor, we say that if there exists the inverse of every element except zero in a ring with identity, then it becomes ring with divisor. Then, (thinking aloud), this becomes something different, because in the integral domain, there is the condition of being without zero divisor and being commutative but no inverse element; for this reason, we cannot say it is a ring with division, I assume.

R: If you designed this concept map again, would there be any part you want to reconfigure?

PT52: It is like reconfiguring, it came to my mind now talking, in fact, can we assume ideal as a commutative ring? (waits confirmation, the researcher is silent). Yet, no we cannot, then, it should be xs=sx but we cannot say this. I think I would not change this concept map.

Group Exhibiting High-Level Mathematical Connection

There were 18 (30%) preservice teachers in this group. These preservice teachers included all of the concepts in their concept maps together with the definitions of these concepts, the relationship between them, and the justification for the relationship. Some preservice teachers in this group designed detailed concepts maps involving examples of the concepts. In the interview transcriptions in this group, clearer expressions in terms of mathematical thinking and connection were encountered compared to their peers in the other two groups. The preservice teacher with the code PT2 in particular, whose concept map and interview transcription are seen below, indicated what kind of relationship each aforementioned algebraic structures have with other structures, and due to which distinctive properties it is called as a new structure, and expressed opinions on cross connections in a detailed way as much as possible, despite not being specified in the map.

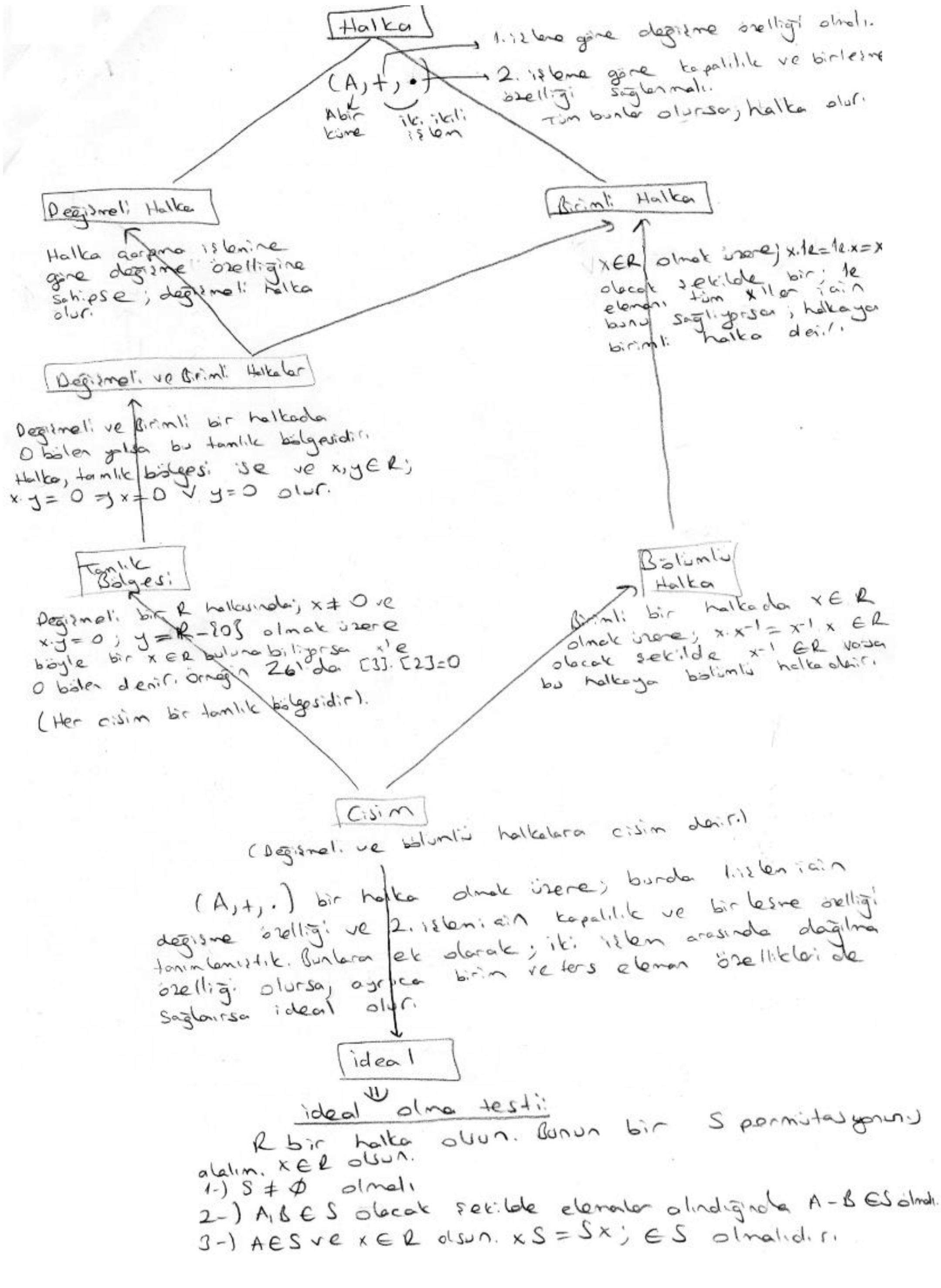

Figure 4. Example Concept Map in the High-Level Group Belonging to PT2.

Figure 4 presents the concept map of the preservice teacher (code PT2) which included all of the concepts, addressed "field" as the upper concept and "ring" as the fundamental concept. The preservice teacher listed other concepts in an accurate hierarchical order and explanations positioned on the arrows. At the end of the concept map, the one-way relationship between "field" and "integral domain" was accurately stated, the "ideal" concept was only related to "field" and the definition of the ideal concept was included with its algebraic properties. As a result, the grading of the preservice teacher with the code PT2 regarding the concept map can be summarized as follows:

Concepts:	8x1=8
Extra Connections:	1x3= 3
Hierarchies:	5x5=25
Cross Connections:	1x10=10
Total	46 points

Excerpt from the Interview Transcript of the Preservice Teacher (code PT2)

R: Could you please explain the concept map you created briefly?

PT2: You asked us to create a concept map involving algebraic structures of rings and special rings, field, integral domain, and ideal. In fact, it was not that difficult because in the lessons, we have talked about the relationship between these concepts.

R: Do you know the definitions and properties of these concepts?

PT2: Yes, in fact, I could write these definitions in the map in a detailed way but since there was not enough space, I was able to write different properties, as we call distinctive properties.

R: What kind of plan were you making when you placed the algebraic structures in the concept map?

PT2: I wanted to order them in an outside-in flow, in fact, I first designed the map in a circular form like the Venn diagram in sets. However, I could not place the connections, then I gave up and made the ordering in this way. For example, when starting from "field", I wrote everything necessary for it to become an "ideal" on the arrow, since "every field is an integral domain", I added zero divisor there and added one of the examples we talked in the course, in fact, I wrote that commutative-divisor ring is called as field but I could not put an arrow from there (pointing to the field concept) to the commutative ring. Well, I could do this when I first drew, but this time commutative-identity ring remained unconnected, for this reason, I erased it. Just like that, I reached the core algebraic structure; namely, ring, by adding the properties. In fact, I think that it would be perfect to go to the groups too, if it was quite long, however, I do not know how to place them, it came to my mind now when I said core.

R: What kind of relationship do you think there is between these structures?

PT2: There is no mutual relationship between all of them, for example, every field is an integral domain but every integral field is not a field. A field is commutative and with divisor but they are not sufficient to be a field. Similarly, for something to be a ring with division, it should be a ring with identity and, in addition, should include inverse element. Just like that, an algebraic structure becomes something new when a property is added, as we talked in the course.

R: What kind of relationship is there between field, integral domain, and ring with division? From your explanation here, what kind of hierarchical ordering should we think of?

PT2: In fact, it would better if this integral domain was a bit lower, because field was going to be between them, a field is both a ring with division and an integral domain. However, there is no relationship between (thinks) integral domain and ring with division.

R: If you designed this concept map again, would there be any part you want to reconfigure?

PT2: I only would make these arrangements, field would be a bit upper and integral domain would be a bit lower, in addition, I would add an arrow between commutative ring and field and write that every field is a commutative ring at the same time. I think I don't have to make any change except these. We could also draw this quite the other way around, we could start from ring and go downwards by adding or it would be a circular concept map as I first attempted. However, in the end, they all indicate the same thing, it does not change.

Results obtained from the concept maps of the preservice teachers from three groups and their interview excerpts were presented in a way illustrating the structure of mathematical connection revealed in a more detailed way. Results are discussed in the next section, the conclusions are accordingly made, and some recommendations were further stated.

CONCLUSION and DISCUSSION

This study aimed to reveal at which level preservice teachers develop mathematical connection skills, an important indicator for meaningful learning; however, positive results were not obtained at the expected level. A considerable number of preservice teachers displayed a low-level mathematical connection even though the researcher, experienced as a teacher, emphasized the relationship of every newly learned concept with previous ones in the lessons. This result was corroborated with the study by Tuluk (2015). As seen in the excerpts from the interviews, the preservice teachers did not make any interpretation of the relationship between the concepts, even though they knew the definitions of concepts separately. This can stem from their unfamiliarity with this type of learning and evaluation types. Therefore, the active use of concept maps in both teaching and evaluation processes can be effective in positive outcomes. Özdemir (2005) has reported that concept maps as a part of the process can strengthen meaningful learning and mathematical connection.

The study showed that preservice teachers who exhibited a mid- to high-level mathematical connection skill experienced fewer difficulties in the definitions of concepts and the relationship between them; however, they did not have enough experience to create an accurate concept map. For this reason, individuals' practice with this type of instrument at early age positively affects their mathematical connection skills, as highlighted in the study by Barody et al. (2000). In addition, in courses containing many abstract concepts such as the course *Introduction to Algebra*, forming concept maps reveals the relationship of every newly encountered concept with the previous one and supports the development of mathematical connection skills.

This study determined mathematical connections using concept maps and found that a vast majority of preservice teachers could do a mid-level connection between the concepts. Learning environments where the hierarchical and connected structure of mathematical concepts is emphasized positively affect the development of mathematical connection skills, as found in previous studies (Bosse, 2003; Karakoç & Alacacı, 2015; Tuluk, 2015; Karslı, 2016). The participants mostly preferred hierarchical and linear concept maps assuming one of the concepts as a central one. Excerpts taken from the interviews indicated that one of the most significant reasons was the need for ordering. The participants –who preferred to locate more than one concept, together with their definitions, on the connection arrows where the common properties were identified– stated that the properties of the concepts should be stressed, not their definitions. Statements on the concept maps designed as a chain or web can be considered as proof that mathematical concepts have a spiral structure.

RECOMMENDATIONS

The concept maps, in this study, created using paper-and-pencil can also be developed as digital maps if participants are competent in using mathematical symbols and notations in a computer environment and the class size is smaller. The participants would be expected to give more explanation and to build a network of relationships.

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