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Abstract

Learning progressions (LPs) gained popularity and importance in the science education field to guide curriculum designers, teachers and researchers as a useful tool to bridge between curriculum, instruction and assessment. Although teachers' professional development can be built through learning progressions these LPs do not describe the ways that teachers can improve as practitioners to scaffold student learning. Research-based, five-step Formative Assessment Design Cycle (FADC) is an iterative professional development cycle which helps teachers to design and effectively use of formative assessments in classroom settings. Within this context, this paper investigates senior biology student teachers' modern genetics knowledge before and after a formative assessment design cycle (FADC) program based on learning progressions.

Introduction

It is a challenging task to help students to have scientific literacy in the domains where scientific progress is fast, phenomena are complex, and cumulative knowledge is daunting (Duncan, Rogat, & Yarden, 2009). Modern genetics is one of these domains with numerous scientific and technological developments in the last century. Each passing day, modern genetics becomes an integral part of our daily lives with advancements such as proving the DNA is the genetic material, clarifying the structure of DNA, mapping out the human genes, cloning, new drugs, and cancer therapies, genetically modified organisms, stem cell research, and genetic tests. Therefore, in the fields of environment, industry, agriculture, health, and technology modern genetics knowledge plays a crucial role for individuals, policymakers, and politicians to make effective decisions. However, research (e.g., Lewis, Leach, & Wood- Robinson, 2000; Longden, 1982; Marbach-Ad & Stavy, 2000) show that learning and teaching genetics is inherently hard. Although teaching genetics starts in the middle school level in many countries such as USA and Turkey, a lot of students lack a basic understanding of genetics and have alternative conceptions about many central ideas of the field when they leave school (Shea, Duncan, Stephenson, 2014). Genetics educators mainly attribute these challenges to many factors. Research indicates that technical language used in genetics complicates the interaction with concepts.

Besides, understanding genetics requires thinking skills in molecular, cellular, organism and population levels of organization (McElhinny, Dougherty, Bowling, & Libarkin, 2014). Students might overcome these difficulties and have deep understandings with carefully designed instruction and with the help of expert teachers who follow the latest developments (Duncan, Rogat, & Yarden, 2009). Teachers on the other side should understand instructional and assessment-oriented ways to scaffold students' progress in an area and to guide them effectively (Heritage, 2008). However, designing effective curricula and professional development programs for teachers to gain expertise also require attention. A practical approach to draw attention to these problems is identifying the evidence on how students learn science and then designing and testing curriculum, assessments and instructional programs based on this evidence (Corcoran, Mosher, & Rogat, 2009). These tasks call the need for evidence-centered models to carefully design and test hypotheses about the curriculum.

Recently, learning progressions (LPs) gained popularity and importance in the science education field (Alonzo & Steedle, 2008; Battista, 2011; Duschl, Maeng, & Sezen, 2011) to guide curriculum designers, teachers and researchers as a useful tool to bridge between curriculum, instruction and assessment (NRC, 2007). Learning progressions (LPs) are defined as "empirically grounded and testable hypotheses about how students' understanding of, and ability to use, core scientific concepts and explanations and related scientific practices grow and become more sophisticated over time, with the appropriate instruction" (Corcoran et al., 2009, p.8). Duncan and Hmelo-Silver (2009) point out that learning progressions have four main features. These are; (1) they focus on a few disciplinary ideas and practices, (2) they are bounded by a lower anchor describing what students know and able to do when they entered the progression and an upper anchor describing what they are expected to know and be able to do by the end of the progression, (3) they represent the intermediate steps between the two anchors and (4) they build a bridge between targeted instruction and curriculum. Learning progressions help teachers to determine productive steps without prescribing a precise curriculum (Alonzo, 2011). They also support their formative assessment practices by promoting the coherence between curriculum, instruction, and assessment in various grades (Alonzo, 2012).

As "a sequence of successively more complex ways of thinking about an idea that might reasonably follow on another in a students' learning" (Smith, Wiser, Anderson, & Krajcik, 2006, p.6) learning progressions suggest that students follow multiple and interactive sequences around important disciplinary specific ideas (e.g., atomic-molecular theory, evolution theory, cellular theory, force, and motion). This approach is different from research which tries to find out the best possible general teaching order for a topic (Hammer & Sikorski, 2015). Previously developed learning progressions focus on different core ideas such as carbon cycling (Anderson, Mohan, & Sharma, 2005; Mohan, Chen, & Anderson, 2009), biodiversity (Songer, Kelcey, & Gotwals, 2009), genetics (Dougherty, 2009; Duncan et.al., 2009; Elmesky, 2012; Roseman, Gogos, Caldwell, & Kurth, 2006), and climate change (Parker, de Los Santos, & Anderson, 2015). There are also educative learning progressions in the field of teacher education such as natural selection (Furtak, Morrison, & Henson, 2010). In these educative examples, Furtak, Thompson, Braaten, and Windschitl (2012) describe how teachers' professional development can be built through learning progressions. These researchers argue that LPs for students may support students' understanding regarding content or/and practices, but these LPs do not describe the ways that teachers can improve as practitioners to scaffold student learning. They mainly address the effective use of formative assessments in classroom settings. Research has shown that formative assessments (or assessment for learning) can produce major improvements in learning and support teachers to become aware of the preconceptions and problem-solving techniques that their students bring into the classroom (Hunt & Pellegrino, 2002).

However, formative assessment has not been adopted widely in many classrooms (Black & William, 1998) and effectively helping teachers to implement a high-quality formative assessment practice is also challenging (Alonzo, 2018; Furtak et al., 2016; Schneider & Randel, 2010). Hunt and Pellegrino (2002, p. 75) attributes this to several factors: (a) the experience of teachers with the material that students are supposed to grasp and the different alternative and problematical ways in which students may fail to grasp it and (b) time requirement for teachers to identify, analyze and respond to the problems of individual problems. Alonzo (2018) recently addresses three challenges that are possible to arise in teachers 'formative assessment practices which are (a) focusing on vocabulary or facts rather than using questions that allow a range of responses and at a higher cognitive demand to support further learning; (b) interpreting students ideas by making holistic judgements about students' ideas as either right or wrong and; (c) responding to students' ideas or providing feedback of a form that will advance students' learning. Studies with pre- and in-service teachers have found out that teachers can shift their approaches to assessment through assessment education and professional experience (DeLuca et al., 2018; Xu & Brown, 2016).

As a professional development approach, Furtak and Heredia (2014) created the Formative Assessment Design Cycle (FADC) that aims to support teacher professional development of formative assessment tasks with the support of a learning progression. FADC is an iterative professional development cycle, and these five steps are (1) explore student ideas, (2) develop tools, (3) practice using the tools (4) enact the tools and (5) reflect on enactment. In one of the studies using FADC, Furtak and her colleagues (2016) worked with nine biology teachers to explore the effect of FADC on the quality of their formative assessment tasks in line with natural selection learning progression. Following these steps with a group of colleagues, teachers can design better formative assessments, develop activities to uncover student ideas, learn more about student thinking and also enhance their understanding of the topic they teach (Furtak & Heredia, 2016). Their results indicated that teachers' ability to interpret student ideas, eliciting questions and feedback increased where the quality of the formative assessment tasks did not increase statistically. Designing and using teacher-created, learning progression aligned formative assessments and guiding students towards more scientific understandings require teachers to rely on deep knowledge to reorganize and respond to student ideas (Furtak et al., 2018).

Studies with pre-service teachers show that courses for pre-service teachers support the development of their knowledge and confidence in assessment theory and practice for having more contemporary conceptions of assessment (DeLuca & Bellara, 2013). So, it also seems possible to use learning progression frameworks in teacher training programs to understand students' common prior ideas, supports their content knowledge through designed interventions, have the knowledge of the strategies in reorganizing the understanding of learners, designing learning progressions based formative assessments and providing useful feedback. Within this context, this paper investigates senior biology student teachers' modern genetics content knowledge before and after a formative assessment design cycle (FADC) program based on learning progressions. In this study, modern genetics is chosen as a focus area because it is both an integral part of the high school Biology curriculum in Turkey and it is a hard-to- teach-and-learn topic as many researchers (e.g., Tekkaya, Özcan, & Sungur, 2001) in the area mentioned. In addition, genetics LPs which are developed and revised in many studies (Duncan et.al., 2009; Elmesky, 2012, Roseman et.al., 2006) gave us a chance to rely on evidence-based knowledge of the field compatible with the nature of learning progressions since genetics ideas seem the most studied core ideas in the discipline of biology.

Method

Participants and Context

The study group consisted of 26 senior biology teachers (20 females, six males) (mean age 23.69) who were enrolled at a national university located at the west part of Turkey. During the study, biology student teachers were taking a Biology Teaching Practice course in their final year at the faculty of education. Until the year 2012, Biology Teaching Program in Turkey used to be a five-year-program with masters without thesis degree and biology student teachers in the study group are the last group in this five-year-program. The program changed to a four-year bachelor's degree program with some alterations in the curriculum.

Study Design

This study leverages a double pre-test post-test quasi-experimental design (Shadish, Cook, & Campbell, 2002) that senior biology student teachers were given the pre-assessment two times, one at the beginning of the fall semester and one at the beginning of the spring semester before the FADC program. The reason to choose this design was to overcome the threats in one group quasi-experimental designs such as internal validity (Harris et al., 2006), selection threat, maturity thread and regression threat (Shadish et al., 2002).

Measures and Sources of Data

Data were collected through Learning Progression-based Assessment of Modern Genetics (LPA-MG). LPA-MG has two versions, one is for high school students (Todd, Romine, & Whitt, 2006), and one is for college students (Todd & Romine, 2016). LPA-MG version 2 is a 34-item 12-construct assessment for college students' knowledge of the domain. Each construct of LPA-MG version 2 aligns mainly with Duncan et al. (2009) genetics learning progressions and its revisions (e.g., Shea & Duncan, 2013; Todd & Kenyon, 2016; Todd et al., 2017). The assessment items in LPA-MG are constructed using the ordered multiple choice (OMC) framework (Briggs, Alonzo, Schwab, & Wilson, 2006). Each construct in the revised progressions (see the outline of the progression levels in Table 1) (Todd et al., 2017) is represented with three assessment items where each item corresponds to different levels for that construct.

Table 1. Outline of the modern genetics progression levels (Todd & Romine, 2016, p. 1678)

Construct	Concept	Assessment items	Levels
A	Genetic information is hierarchically organized	A (V1, V2 and V3combined)	0-6
B	Genes code for proteins	V4, V5, V6	0-6
C1	Proteins do the work of the cell	V7, V8, V9	0-5
C2	Proteins connect genes and traits	V10, V11, V12	0-6
D	Cells express different genes	V13, V14, V15	0-6
E	Genetic information is passed on to offspring	V16, V17, V18	0-5
F	There are patterns of correlation between genes and traits	V19, V20, V21	0-5
G1	DNA varies between and within species	V22, V23, V24	0-6
G2	Changes to genetic information result in increased variation and can drive evolution	V25, V26, V27	0-5

H	The environment interacts with genetic information	V28, V29, V30	0-6
I	Only mutations in gametes can be passed to offspring	V31, V32, V33	0-4
J	Gene expression can change at any point during an organism's lifespan	V34, V35, V36	0-4

The Turkish version of LPA-MG version 2 was adapted to Turkish culture for the first author's doctoral dissertation. After this process, LPA-MG version 2 was used in this study as pre-and post-assessment to show if the FADC program contributes to biology student teachers' modern genetics learning progressions.

FADC Program

FADC program featured biology student teachers' participating in twice a week sessions. The sessions were conducted for about 90 minutes during teaching practice academic course hours. In total, biology student teachers participated in 16 sessions (four preparation sessions and 12 FADC sessions) for eight weeks.

Preparation Sessions

Since FADC mainly designed for teachers, it is thought that biology student teachers need to participate in four preparation sessions for two weeks before the program. In these four preparation sessions following themes are studied with senior biology student teachers to increase their readiness for the main steps of FADC.

1. Turkish National Biology Curriculum, Curriculum materials such as textbooks, annual/weekly/daily plans and other materials.
2. What is an assessment? Assessment types and mainly formative assessment classroom assessment techniques (FACTs).
3. Research on modern genetics education (articles and dissertations primarily in Turkish literature)
4. Mapping students' conceptual understandings regarding misconceptions and learning difficulties: What, when, how to teach and how to assess?

FADC Sessions

In FADC sessions, 26 biology student teachers worked in 6 groups to follow the steps of Formative Assessment Design Cycle (Figure 1). At each step of the FADC, biology student teachers relied upon the Modern Genetic Learning Progression (Duncan et al., 2009) to guide them in the domain of modern genetics.

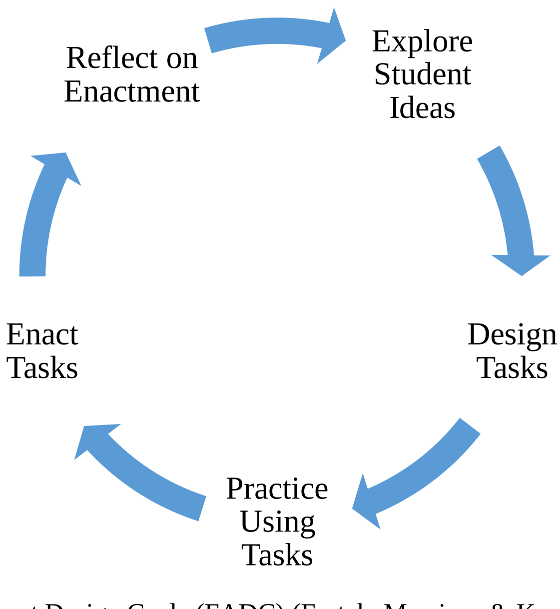


Figure 1. Formative Assessment Design Cycle (FADC) (Furtak, Morrison & Kroog, 2014; Furtak & Heredia, 2016)

The 1st session began with the examination of biology student teachers' work on preparation sessions regarding exploring student ideas based on the learning progression framework (Duncan et.al.,2009). Working in 6 small groups, senior biology student teachers listed the ideas (such as misconceptions and learning difficulties) about the 12 constructs of the modern genetics LP framework. In the 2nd to 5th sessions, they created four content representations (CoRes) listed below around disciplinary core ideas again working in small groups to deepen their knowledge in the domain of modern genetics (Step 1: Explore Student Ideas). Table 2 presents biology student teachers' list of possible student misconceptions in modern genetics' core ideas.

Table 2. Biology student teachers' list of possible student misconceptions in modern genetics' core ideas

<table>
<tr><th>CoRe #</th><th colspan="2">Possible misconceptions</th><th>f (N=6)</th></tr>
<tr><td>1</td><td colspan="2">Students might not relate concepts such as chromosome-DNA-gene</td><td>4</td></tr>
<tr><td>1</td><td colspan="2">Students might not grasp that single-celled organisms do not have chromosomes</td><td>1</td></tr>
<tr><td>1</td><td colspan="2">Students might think DNA carries something to somewhere when they hear "DNA carries the genetic information"</td><td>3</td></tr>
<tr><td rowspan="2">1</td><td rowspan="2">Students might think if we take DNA from one organism and put it into a different organism DNA does not work because…</td><td>Organisms can only use DNA from their own species</td><td>4</td></tr>
<tr><td>The structure of DNA is different in all organisms</td><td>2</td></tr>
<tr><td>1</td><td colspan="2">Students might think viruses have DNA and RNA together</td><td>2</td></tr>
<tr><td>1</td><td colspan="2">Students might think there is only one DNA in all organisms rather than in every cell</td><td>3</td></tr>
</table>

***CoRe # = Content Representation Number**

1 *It is the molecule DNA that carries the genetic instructions used in growth, development, function and reproduction in all types of living organisms (except some viruses).*

In the 6th and 7th sessions study groups worked on designing formative assessment tasks (probes) for each construct of the modern genetics learning progression. In the 8th session, they presented their probes to discuss in a whole group brainstorming session, and they noted the necessary revisions (Step 2: Desing Tasks). They, then, started to review and revise their probes in the 9th session (Step 3: Practice Using Tasks).

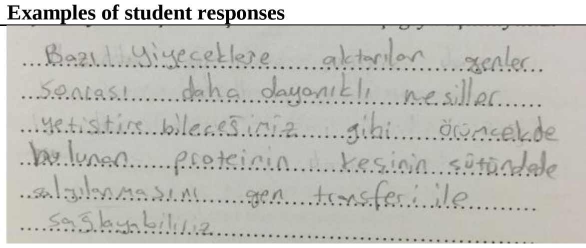
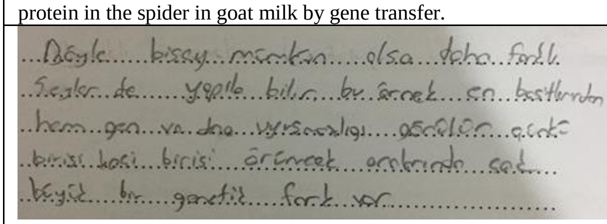
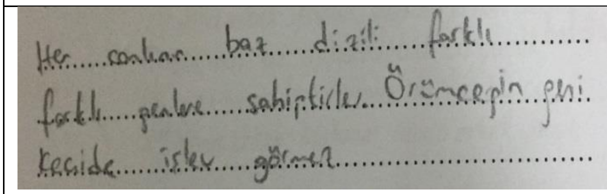
Before the *10th session* they collected data from high school students with their formative assessment probes (Step 4: Enact Tasks), and they evaluated the probes and analyzed high school students' ideas in the last two sessions (*11th and 12nd*) (Step 5: Reflect on Enactment). Table 3 presents initial and revised version of one formative assessment probe designed by senior biology student teachers for construct A and examples of responses to this probe.

Data Analysis

As mentioned above, LPA-MG version 2 is an ordered multiple-choice (OMC) assessment instrument including 34 items. Before starting data analysis, data obtained by conducting LPA-MG version 2 as pre-assessment 1, pre-assessment 2 and post-assessment were scored based on the mapped levels of the learning progression (Todd & Romine, 2016). After scoring, biology student teachers' levels in all three times were compared using Repeated Measures ANOVA statistics to see if FADC program supported their modern genetics content knowledge.

Repeated Measures ANOVA statistics provided information about the overall significant difference between the means at the different time points and where those differences occurred. After conducting repeated measures ANOVA statistics first, the results of Mauchly's sphericity test interpreted regarding the assumption of sphericity. These results showed that Mauchly's sphericity test was not significant ($p> .05$) for the constructs A, F, G2, and H, in other words, the assumption of sphericity was not violated. For other constructs in which the assumption of sphericity is violated it was necessary to make corrections (ε) in the degrees of freedom used for calculating the p-value. Since the assumption of sphericity is not difficult to be violated (Weinfurt, 2000) and Mauchly's test of sphericity is seen as a weak method to determine variations in small samples (Kesselman et al., 1980) Greenhouse-Geisser results and pairwise comparisons were interpreted for all constructs to see the significant differences between the means and where those differences occurred.

Table 3. Initial and revised version of one formative assessment probe for construct A

Construct	Initial probe	Revised Probe	Examples of student responses
A: Genetic information is hierarchically organized	Scientists transferred the spider genes to goats and produced silk fibers in goat milk. This silk is very flexible, durable and lightweight and is used in military clothing, medical equipment and tennis rackets. **Which of the following inferences cannot be reached according to this study and its results?** A)Only goats carrying this gene may produce milk containing silk proteins B)When we transfer this gene to goats their foods also change. C)What the goats eat might have an effect on the quality of silk fibers. D)A gene can have the same function in different living things.	The silk fibers used by spiders to make silk are highly flexible, durable and lightweight. For this reason, this silk is used in military garments, medical equipment and tennis rackets. These strands consist of a special silk protein. Scientists transferred the spider genes that enable the synthesis of this protein to goats to produce silk fibers in goat milk. **A biology teacher asked his students to read this reading in biology class and then asked them for their opinions on the subject. The answers given by some of the students in the classroom are as follows:** A)Ali thinks that it is not possible to transfer genes from spiders to goats because spiders do not have genes. B)Simge thinks that these genes will not function in the goat's cells even if the genes are transferred from the spiders to the goats since each living thing has its own unique genes. C)Naz thinks that goat's cells can produce silk fibers in goat's milk using spider genes. D)Erdem thinks that this information is correct because the structure of genetic material is the same in all living things and the working mechanism will be the same. Which student's answer is most accurate in your opinion? Mark the answer and explain why you chose it.	 Translation: We can grow more resistant generations after the genes transferred to some foods, or we can provide the secretion of the protein in the spider in goat milk by gene transfer.  Translation: If such a thing were possible, different things could have been done. According to this example, both gene and DNA mismatch occur. Because there is a huge genetic difference between a goat and a spider.  Translation: The base sequence of each living thing has different genes. A spider's gene does not function in a goat

Findings

In this section, we present the findings of the study regarding the constructs of LPA-MG version 2. Biology student teachers' scores and repeated measures ANOVA calculations were interpreted using the outline of modern genetics progression and condensed descriptions of levels as in Todd, Romine & Whitt (2017, p.37-39). Table 4 presents items, item focus, biology student teachers' most probable levels in assessments, pre- and post-descriptions of the study group, repeated measures ANOVA calculations and where the significant change happened (if there is) between measures.

Table 4. ANOVA results

Construct	Items & Item focus	Most Probable Levels			Pre-description	Post-description	Repeated Measures ANOVA Results	Significant change between measures
		Pre 1	Pre2	Post				
A: Genetic information is hierarchically organized	V1, V2, V3 the relationship between 6 concepts: genes, DNA, chromosomes, nucleotides/bases, cells, and genomes	5	5	6	5 connections between 6 concepts	All 6 correct	F(1.821, 45.516)= 39.912, p=0.001 < .05, partial η2 = .615.	between pre-assessment 2 and post-assessment
B: Genes code for proteins	V4, V5, V6 why is DNA sometimes called the genetic code, the purpose of genes and how are genes specify traits in an organism	4	4	6	genes code for cell entities	genes translated into proteins	F(1.555, 38.881)= 10.435, p=0.001 < .05, partial η2 = .294	between pre-assessment 2 and post-assessment
C1: Proteins do the work of the cell	V7, V8, V9 what proteins do, why do proteins have different functions and what determines the function of different proteins	4	4	5	protein function depends on structure	protein structure and function depends on amino acids in the protein	F(1.536, 38.402)= 9.973, p=0.001 < .05, partial η2 = .285	between pre-assessment 2 and post-assessment
C2: Proteins connect genes and traits	V10, V11, V12 changes to genes change protein functions to change traits	5	5	6	changes to genes change amino acids in proteins	changes to genes change protein functions to change traits	F(1.249, 31.222)= 2.403, p=0.125 > .05, partial η2 = .088	No significant difference between measures
D: Cells express different genes	V13, V14, V15 the difference of different cells, the relationship between genes, mRNA and proteins and the description of cells	4	4	6	different cells have different proteins for their functions) and level 5 (somatic cells have the same DNA but different proteins	somatic cells have the same DNA to express different proteins	F(1.529, 38.223)= 10.670, p=0.001 < .05, partial η2 = .299	Between pre-assessment 2 and post-assessment
E: Genetic information is passed on to offspring	V16, V17, V18 independent assortment of alleles, meiosis and dihybrid crosses	2	2	3	offspring get half of DNA from each parent	alleles are randomly asserted	F(1.502, 37.543)= 9.813, p=0.001 < .05, partial η2 = .282	Between pre-assessment 2 and post-assessment
F: There are patterns of correlations between genes and traits	V19, V20, V21 dominant-recessive relationships and their connection with protein interactions	3	3	4	organisms get one allele per parent, and traits can be predicted	alleles differ in sequence which affects proteins to give trait variations	F(1.741, 43.514)= 2.798, p=0.079 > .05, partial η2 = .101	No significant difference between measures

Table 4 Cont.

G1: DNA varies between and within species	V22, V23, V24 why do organisms look different, DNA and gene products and genetic differences between and within species	3	3	5	organisms have different DNA even within a species	organisms of different species have some similar and some different DNA	F(1.627, 40.683)= 22.677, p=0.001 < .05, partial η2 = .476	between pre-assessment 2 and post-assessment
G2: Changes to genetic information result in increased variation and can drive evolution	V25, V26, V27 changes in DNA, genetic variation and DNA mutations	3	3	4	changes to an organism can be beneficial or harmful	DNA changes can be beneficial, neutral, or harmful, and can change protein structure/functio n	F(1.771, 44.287)= 21.722, p=0.001 < .05, partial η2 = .465	between pre-assessment 2 and post-assessment
H: The environment interacts with genetic information	V28, V29, V30 how the environment affects individuals and the genetic and environmental effects on complex traits	5	5	6	environment can change type and amount of proteins that influence cell function	environment can change genes which change proteins or change gene expression of proteins	F(1.861, 46.516)= 21.126, p=0.001 < .05, partial η2 = .458	between pre-assessment 2 and post-assessment
I: Only mutations in gametes can be passed down to offspring	V31, V32, V33 the inheritance of mutations by giving examples such as skin cancer and breast cancer	3	3	4	only mutations in gametes can be passed down to offspring	only mutations in gametes can be passed down to offspring and mutations to somatic cells can only be passed on to descendant cells	F(1.473, 36.817)= 5.308, p=0.016 < .05, partial η2 = .175	between pre-assessment 2 and post-assessment
J: Gene expression can change at any point during an organism's lifespan	V34, V35, V36 how the expression of genes regulated or controlled, at what times during an individual's life can gene expression change and the reason for differences in identical twin mice	3	3	4	genes can be turned on and/or off only during key life stages	gene expression can change at any point during one's life	F(1.371, 34.265)= 15.867, p=0.001 < .05, partial η2 = .388	between pre-assessment 2 and post-assessment

☐ Constructs with a significant change to the upper anchor ☐ Constructs with a significant change to the next levels ☐ Constructs without a significant change

As summarized in Table 3, the findings obtained by using LPA-MG version 2 as pre-assessments before the FADC program indicated that senior biology student teachers' knowledge levels are lower than it is expected. When the findings are examined in terms of each construct, it was found that senior biology student teachers' scores were lower for constructs E, G1 and G2 at the beginning of the year. Since construct E deals with how genetic information is passed on to offspring, these lower scores indicated that senior biology student teachers lacked knowledge about the details of meiosis. The lower pre-assessment1 scores obtained from Construct G2 indicated that senior biology student teachers lack the fundamental knowledge of evolution.

Besides, senior biology student teachers in our study group had significant changes in constructs A, B, C1, D, E, G1, G2, H, I and J of modern genetics learning progression. However, for constructs E, G1 and G2 senior biology student teachers' scores are not as it is expected since their understanding levels the upper anchors of the modern genetics' learning progression (3/5 in construct E, 5/6 in construct G1 and 4/5 in construct G2). We found no significant difference between measures in constructs C2 and F. For constructs C2 and F it shows that senior biology student teachers were able to understand that changes to genes change amino acids in proteins, but they could not properly relate this knowledge with the protein functions and how the proteins give trait variations.

Results and Discussion

Conceptual change is often associated with the re-constructing of students' existing knowledge. In contrast, conceptual change is usually determined relatively merely by associating the difference in content knowledge with pre-test post-test results after different interventions (Todd, Romine & Correa-Menendez, 2017). However, providing the right answer in the tests is not an indicator of understanding the problem because students can correctly answer the question without using the cause-effect relation or using some personal algorithms (Hackling & Treagust, 1984; Kinnear, 1983). Almost all of the senior biology teachers participating in this study have learned a lot about modern genetics during their school years and five years of university life, and it is difficult to identify their existing knowledge considering they have covered almost all of the concepts in modern genetic learning progression throughout their education life. However, studies have shown the existence of misconceptions on genetics even after years of education (Banet & Ayuso, 2000). Consistent with these ideas, the findings obtained by using LPA-MG version 2 as pre-assessments before the FADC program indicated that their knowledge levels are lower than it is expected. This suggests that biology student teachers did not have a holistic knowledge of modern genetics-related topics even though they are seniors. Studies have shown that students' inability to comprehend genetics issues is due to the inconsistent and often non-historically (in a series of linear and consistent developments rather than in a variety of contexts that have been set up and employed in specific contexts) presentation of models about genes and their mechanisms in living systems (dos Santos et.al., 2012). Although these historical models are frequently used in genetics education, they may cause over-simplified and deterministic ideas by making central concepts difficult to understand for students (Gericke & Hagberg, 2010). Since learning progressions potentially define how learners develop their understanding over time by organizing the content (Smith et al., 2006; Duschl et al., 2007; Shin et al., 2009), it has served as an integrated curriculum framework for biology student teacher participants in this study. FADC program helped senior biology student teachers to evaluate basic concepts, ideas, and misconceptions that students may have and to explore formative assessment strategies which aimed to eliminate these misconceptions from a teacher's point of view. In this respect, this study allowed biology student teachers to look at modern genetics form a more holistic perspective and to progress from lower levels to higher levels over time as their knowledge increases and also contributed to learning progressions studies by providing further empirical evidence since they held consistent ideas with the levels in each construct of modern genetics LP. These results support the research by Todd, Romine, and Whitt (2017) which used the first version of LPA-MG and showed that high-school students gained meaningful improvements after 23-weeks genetic instruction.

When the findings are examined in terms of each construct, it was found that senior biology student teachers' scores were lower for constructs E (Genetic information is passed on to offspring), G1(Changes to genetic information result in increased variation and can drive evolution) and G2 (DNA varies between and within species) at the beginning of the year. Since construct E deals with how genetic information is passed on to offspring, these lower scores indicated that senior biology student teachers lacked knowledge about the details of meiosis. It is stated in many previous studies (e.g., Bahar, Johnstone & Hansell, 1999; Çakır & Crawford, 2001; Freidenreich et al., 2011) that biology student teachers considered topic related to mitosis and meiosis challenging to understand. Banet and Ayuso (2000; 2003), in their study about the location and transmission of genetic information on high school students, emphasize that mitosis and meiosis topics are the basis of heredity, and therefore there is a need to closely relate the cell division process with the transmission of inheritance knowledge in students. They also stated that when students understand meiosis, the formation of haploid gametes and the diversity of heredity information carried by the ovules/spermazoids, it will provide a better understanding of the mechanisms of evolution. The lower pre-assessment1 scores obtained from Construct G2 which describes the relationship between variation and evolution indicated that senior biology student teachers lack the fundamental knowledge of evolution, one of the central ideas of biology. Despite this pivotal role, it is emphasized in many studies (e.g., Smith, 2010; Kalinowski, Leonard & Andrews, 2010) that evolution is conceptually difficult for students at all levels of education including university level. In their study with university-level biology majors Speth et al. (2014), stated that after enrolling in a period of genetics, evolution and ecology classes, one-third of the students had difficulty in integrating the molecular basis of variation in their explanatory frameworks even after getting formative assessment and application feedback. On the other hand, senior biology student teachers in this study took evolution courses in their last semester of high school which in Turkey also considered a major problem because the university placement system forces them not to learn these last subjects extensively, and they also took Evolution in their final semester of university which is after they took pre-assessment 1. This two situations and related literature seemed like explaining this difficulty of the participants for this construct.

Interpreting senior biology student teachers' scores for constructs C1 (proteins do the work of the cell) and C2 (proteins connect genes and traits) it is possible to say that their scores differs from studies showing that university- level students (e.g., Todd & Romine, 2016), high school students (e.g., Duncan & Tseng, 2011; Todd & Kenyon, 2016) and secondary school students (e.g., Freidenreich et al., 2011) have issues to explain how proteins connect genes and traits. However, since senior biology students also received higher scores for Construct C1, which is related to the functions of proteins, might be a determinant of their higher scores for Construct C2. Stewart, Cartier, and Passmore (2005) define three conceptual models (genetic, meiotic and molecular models) for genetics literacy. Proteins and their functions are within the scope of the molecular model which plays a mediating role for students to relate genetics and meiotic models. For this reason, these higher scores for constructs C1 and C2 seemed to contribute their understanding of the meiotic and genetic models after the FADC program.

Overall, it was concluded that senior biology student teachers had significant gains after FADC program for all constructs of the modern genetics learning progression except for constructs C2 and F. However, although there were increases in senior biology student teachers' mean scores for construct F after FADC program; it showed that they had problems to understand how dominant and recessive relationships are explained by protein interactions. This result is in line with the results of Todd's (2013) doctoral study with 10th-grade students to test the modern genetics learning progression. When all the results related to supporting senior biology student teachers' modern genetics knowledge through the FADC program based on learning progressions by using LPA-MG2 are evaluated together, it is seen that these results also support the idea that the development of understanding about a subject requires targeted curriculum and teaching as it is emphasized in the research in learning progressions.

Recommendations

Based on the results of the study, the following recommendations can be made for teacher education:

- It is critical to determine student teachers' pre-understandings in teacher education. If they have misconceptions, it is possible that they mislead their future students. For this reason, it should be considered as one of the important responsibilities of teacher education in determining the important areas where students experience difficulties and shaping them to shape their teaching and self-understanding.
- Although the senior biology student teachers in this study have taken various courses related to modern genetics for many years, the fact that their content knowledge is limited indicates that there are some problems in the acquisition of content knowledge. In this study, it is seen that content knowledge can be supported through a FADC program. It is recommended for teacher education institutions to support their students' theoretical knowledge by integrating how that subject matter can be taught in different contexts as a way to associate theory and practice.
- Since modern genetics learning progression studies are generally conducted with students. Adapting and using this framework as an "educative learning progression" is thought to provide essential contributions to genetics education. Besides, providing step-by-step professional development programs such as FADC in this study is believed to contribute their future pedagogical practices.

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