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CREATIVE THINKING, STRENGTHENING GIFTED PROGRAMS, AND ACCELERATION

Enhanced Open-Mindedness and Problem Finding Among Gifted Female Students Involved in Future Robotics Design

Alaa Eldin A. Ayoub, Ahmed M. Abdulla Alabbasi, Amal M. Alsubaie, Mark A. Runco, and Selcuk Acar

ABSTRACT
This article investigated the impact of a robotic-based enrichment program on problem finding (PF) and active-openminded thinking skills (AOT) in 60 gifted female students (eighth and ninth graders) from the Eastern region of Saudi Arabia. The participants were randomly selected from several cohorts of gifted students who participated in an enrichment summer program. The enrichment program lasted for 4 weeks. The study instruments included the Problem Generation (PG) test and the Active-Openminded Thinking (AOT) scale, which were administered to the participants at the beginning of the program and at the end of the program. The change in the measured program outcomes after attending the robotics intervention program was assessed by a regression model, where posttest scores were regressed on pretest scores. The results revealed differences for the three subscales of AOT: Belief Identification (BI), Flexible Thinking (FT), and Dogmatic Thinking (DT) as well as the total score of the AOT in favor of posttest condition. Moreover, the results indicated that ninth graders benefited more from the enrichment program than eighth graders did. As for PF, fluency scores showed no significant differences between pretest and posttest, while originality scores were significantly higher for the posttest scores when compared to the pretest scores.

KEYWORDS
active-openminded thinking; enrichment program; gifted students; problem finding; robotics

Every gifted program has two primary objectives: first, to identify those who are eligible to receive advanced learning experiences; second, to provide students with differentiated educational programs and services that meet their cognitive, social, and emotional needs (Renzulli, 2005, 2012). Identifying gifted and talented students is based on the definition of "gifted." However, there is neither one accepted definition for this nor a specific way of identifying gifted and talented learners. There are comprehensive lists containing conceptions about being gifted (Cross & Olszewski-Kubilius, 2020; Sternberg & Ambrose, 2021; Sternberg & Davidson, 2005). Definitions have evolved from IQ being the sole indicator of being gifted to an array of indicators that acknowledge the multidimensional nature of being gifted (e.g., Gagné, 2004; Gardner, 1983; Heller et al., 2005; Renzulli, 2005; Sternberg, 2003; Tannenbaum, 2003). There also has been a shift toward conceptions that focus on the domain-specific aspect of being gifted rather than being generally, intellectually gifted (e.g., Gagné, 2004; Gardner, 1983; Runco, 2005; VanTassel-Baska, 2005). According to this multidimensional view, there are gifted students in science, technology, engineering, arts, and mathematics (STEAM) as well as other areas of exceptionality, such as leadership (Matthews, 2004) and sports (Richard et al., 2017).

There are also different programs and services that support gifted learners. Renzulli (1986) made a clear distinction between *schoolhouse giftedness* and *creative-productive giftedness*. Moreover, Gagné's (2005) Differentiated Model of Giftedness and Talent (DMGT) focuses on how being gifted can be transformed into talents in specific domains. Consequently, programs and services for gifted and talented students, such as acceleration, pullout programs, curriculum differentiation, and enrichment programs recognize that gifted students can transform their gifts into talents in specific domains (Albert, 1980).

Enrichment programs, defined as activities that go beyond the existing curriculum, are well known services that are used to maximize gifted students' achievement in basic skills, deepening their knowledge about a specific topic or theme, enhancing their thinking skills (Davis et al., 2011; Kim, 2016; Renzulli, 2003). Enrichment programs usually consist of two elements, namely delivery method and process (Davis et al., 2011).

Examples of delivery methods include independent study, field trips, summer programs, and technology use. These four strategies are primarily important to the current study, as will be discussed in the methods section. The process component of an enrichment program may include one or several assessments for gifted individuals, such as (a) problem-based learning (PBL); (b) divergent thinking skills, for example, fluency, flexibility, originality, and elaboration; (c) critical thinking skills,

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such as bias evaluation, inductive and deductive reasoning, and evaluation; (d) creative problem solving (CPS); (e) problem finding (PF); and (f) metacognitive skills, for example, planning, monitoring, and evaluation.

Enrichment programs use specific content and are designed for a specific goal. Thus, a number of enrichment programs in specific areas have been developed, including *mathematics* (e.g., McCoach et al., 2014; Young et al., 2011), *self-concept* (Cunningham & Rinn, 2007; Dai et al., 2013), *academic achievement* (Al-Zoubi, 2018; Lee et al., 2010), *reading* (Bishop, 1981; Reis & Boeve, 2009), and *STEAM* (Assouline et al., 2017; Dailey et al., 2018; Mun & Hertzog, 2018).

Many gifted programs include robotics because it provides an opportunity for students to engage in science, technology, engineering, and problem solving as well as teamwork. Robots are a critical part in every field, including medicine, industry, and education (Paul, 2009, p. 742). Thus, it is not surprising that many enrichment programs on robotics have been designed and implemented in the last 2 decades (e.g., Al-Hamdan et al., 2017; Gubbels et al., 2014; Yoon et al., 2020).

This study evaluated a summer program that encouraged students to engage in problem finding (PF) and active open-minded thinking skills (AOT). PF is "the ability to imagine, look for discrepancies and apparent contradictions, and entertain new hypotheses about old problems/issues or generate entirely novel questions or problems to be solved" (Carson & Runco, 1999, p. 140). AOT encompasses "the willingness to consider alternative opinions, the sensitivity to evidence contradictory to current beliefs, the willingness to postpone closure, and reflective thought" (Stanovich & Toplak, 2019, p. 156). PF is important because it is part of the creative process (Runco & Chand, 1995), and it is considered the first step in almost all models of creative thinking (Abdulla & Cramond, 2018; Abdulla et al., 2020). Given the nature of the enrichment program on robotics, which requires students to design and develop new robots for a problem that is ill-defined, PF should be an essential skill that teachers aim at inculcating. AOT is also important in such programs because it entails flexible thinking and the ability to resist premature closure. Both are creative thinking skills (Torrance, 1966).

Literature review: Enrichment programs on robotics

A new emphasis in some gifted programs is robotics. The rationale behind such an interest in robotics is that future jobs, especially in scientific fields, require advanced knowledge in robot programming language. Moreover, some reports estimate that in less than two decades, about half of all current jobs will be replaced by artificial intelligence in some parts of the world (Coxon et al., 2018).

A search for empirical studies that examined the effectiveness of robotic-based enrichment programs resulted in several articles. Ramli et al. (2011) examined the effect of a 3-week enrichment program in robotics on students' basic knowledge of robotics. The sample consisted of 48 middle school gifted students. A one group pretest-posttest design was used, which showed a significant gain in gifted students' knowledge of robotics.

Coxon et al. (2018) conducted an experimental study using a one group pretest-posttest design to evaluate the effect of a special curriculum unit, Children Using Robotics for Engineering, Science, Technology, and Math (CREST-M) on math achievement. The sample consisted of 25 male and 20 female fourth and fifth graders who were gifted students. They attended a 30-hr summer program on CREST-M. The results indicated that participating in the CREST-M enrichment curriculum resulted in a significant difference in math achievement between pretest and posttest, with a large effect size ($d = 0.72$). No gender difference was reported.

Pinasa and Srisook (2019) assessed the impact of robotics-related learning activities on creativity and attitude for 92 high school students. The activities were conducted over 18 sessions. A pretest-posttest design was used, and the results indicated that such activities significantly increased students' fluency and flexibility skills in addition to their attitude toward learning activities in the project.

Robinson et al. (2014) investigated the effect of a science focused STEM intervention on gifted students' knowledge of science. Although the enrichment program was not about robotics, some units related to engineering were included in the curriculum (Robinson et al., 2014, p. 197). The experimental group in the year 1 summer program consisted of 87 gifted students, while the control group consisted of 70 gifted students. As for year 2 summer program, 67 gifted students represented the experimental group, while the control group consisted of 60 gifted students. The results indicated significant differences between the experimental and control groups regarding all the dependent variables: (a) science process skills, (b) student knowledge of science content, and (c) student knowledge of science concepts.

Dailey et al. (2018) conducted an experimental study that aimed at answering two main questions. First, how did students' knowledge of science and engineering practices change after participating in an engineering camp? Second, how were students able to use engineering design processes during the engineering challenges? (Dailey et al., 2018, p. 100). The sample consisted of 59 students attending the STEMulate Engineering Academy in year 1, and 62 students attending in year 2. Fourteen training hours were distributed across 4 days for each year. Subject content from an Engineering Is Elementary (EIE) curriculum was used. The first dependent variable was science content knowledge; the second dependent variable was Engineering Design Process (EDP; Ask, Imagine, Plan, Create, and Improve). Results for the year 1 students showed a significant difference between pretest and posttest for both grades 4 and 5, for both assessments. As for year 2, the results showed a significant difference for grades 3 to 5, for both assessments.

So far, only three studies explicitly developed a robotics-based enrichment program (i.e., Coxon et al., 2018; Pinasa & Srisook, 2019; Ramli et al., 2011), and only one aimed at enhancing students' thinking skills (i.e., Pinasa & Srisook, 2019). Finally, all of those studies used a one group pretest-posttest design. The other studies developed enrichment programs that only partly addressed topics related to robotics (i.e., Dailey et al., 2018; Robinson et al., 2014).

The current investigation was designed to extend the research on robotics-based enrichment. The main purpose of this study is to examine the effect of a summer enrichment program in robotics on two cognitive processes essential in designing novel robotic products: PF and AOT. Another contribution of this study is that the sample consisted of female students. This sample represents a population that is underrepresented in the STEM fields (Makarova et al., 2019; Wang & Degol, 2017). The American Association of University Women (n.d.) estimated that women make up only 28% of the workforce in the STEM fields [science, technology, engineering, and mathematics], and the U.S. Bureau of Labor Statistics (2019) reported that women make up only 11.7% of the workforce in architectural and engineering management (Sargent, 2013–2017). Thus, any effort that aims to encourage women to pursue a STEM field should be praised.

Methods

Participants

After receiving an official approval from the Ethics Committee at the College of Graduate Studies at the Arabian Gulf University as well as the Ministry of Education in Saudi Arabia, the study participants were randomly selected from several cohorts of gifted students who participated in an enrichment program on robotics during the summer of 2018. The sample consisted of 60 middle school female, gifted students from the Eastern region of Saudi Arabia, who were in the eighth and ninth grades. The participants' mean age was 14.2 years (SD = 0.67).

The selection criteria included those who were in the top 5% of an ability test developed by the National Center for Assessment in Saudi Arabia, which assesses analytical thinking, reading comprehension, and logical reasoning as well as those with Grade Point Average (GPA) above the 90th percentile. All participants were asked to sign a consent form. Their parents were also sent consent forms.

Enrichment program

The robotics program was designed to meet the cognitive needs of eighth and ninth grade students who are gifted. It consisted of four components: (a) a scientific unit (content), (b) an enrichment unit, (c) scientific trips, and (d) competitions. Moreover, different topics related to physics and mathematics, such as torque, covariant kinematics/dynamics, algebra, and algorithms were introduced. The *enrichment unit* targeted several areas, such as presentation skills, self-management, and project management. Additionally, students learned about research ethics, innovation cycles, and patents. The third component, *scientific trips*, introduced students to experts as well as other university faculty members in the field of robotics. Finally, the *competition* phase consisted of the opportunity to present their work to a panel of experts who assessed the products' originality. The panel also provided feedback regarding the assembling technique and project design. To summarize, the enrichment program in robotics was aimed at enhancing collaboration whereby groups of students designed a robot with different functions. They were free to design their own robots, which suggests that PF was an important variable in this study. The program spanned over 4 weeks with a total of 30 intensive sessions.

Procedure

Data were collected from students who participated in enrichment programs held annually by King Abdulaziz and his Companions Foundation for Giftedness and Creativity (Mawhiba) in Saudi Arabia. The summer enrichment programs aim at meeting the cognitive, emotional, social, and physical needs of gifted students. The pretest was conducted 2 days before the beginning of the program, while the posttest was conducted on the final day of the program. The duration between the pretest and posttests was 30 days. The third author visited the summer program and met with students to gain familiarity with them without discussing anything related to the study instruments. At the end of the visit, the third author informed participants that she would visit them the following week to administer some activities (the term "test" was not used at all).

Instruments

Two instruments were used to assess the students prior to and after the enrichment program: The Active Openminded Thinking Scale and the Problem Generation Test. The enrichment program in robotics represented the independent variable, while the AOT and PF represented the dependent variables.

AOT scale

Active open-minded thinking was assessed using a scale devised by Ibrahim et al. (2010) based on the AOT scale developed by Stanovich and West (1997). The AOT is a 41-item scale, which consists of 3 subscales: (a) Belief Identification (BI), (b) Dogmatic Thinking (DT), (c) Flexible Thinking (FT), and total AOT score. Responses were indicated on a 5-point Likert scale ranging from 1 = *strongly disagree* to 5 = *strongly agree*. Since the AOT scale was not used with a Saudi sample prior to this, a pilot study was conducted to test the validity and reliability of the scale on 217 middle school students in Saudi Arabia. Evidence of the validity and reliability of the AOT scale are presented under Results.

Problem Generation test

The Problem Generation (PG) test from the rCAB creativity test battery (Runco & Acar, 2010; Runco et al., 2016; www.creativitytestingservices.com) was used to assess participants' PF ability. The PG test consists of three open-ended tasks that ask participants to list as many problems as they can. These problems are related to home and school, life situations, and health and wellbeing. An example of a PG task is: List problems with your health or physical well-being (illness, exercise, diet). Again, these can be real (from your experience, or that of someone you know), hypothetical, or imaginary. The more problems you list, the better.

Testing the discriminant validity showed that the PG test was unrelated to the Preliminary Scholastic Aptitude Test (r = .03 to .19; Runco & Okuda, 1988). In a recent study that was conducted on middle school Arab students, the reliability coefficients for fluency and originality in the PG test were .83 and .70, respectively, indicating a good reliability (Abdulla Alabbasi et al., 2021).

Results

Confirmatory factor analysis (CFA) was used to examine the construct validity of the AOT in a sample of 217 students. The fit indices of the scale were good: $\chi 2/df$ = 1.28, RMSEA = 0.047, GFI = 0.91, AGFI = 0.90, NFI = 0.92. The reliability coefficients for the subscales were estimated using Cronbach's alpha: .79 for BI, .80 for DT, .78 for FT, and .82 for the total AOT score. The reliability of PG test in the current study was also good: (.85) for fluency, and (.83) for originality (5% cut off).

Following the Cohen et al. (2003) approach, changes in the measured program outcomes after attending the robotics intervention program were assessed by regressing posttest scores on pretest scores (Cohen et al., 2003, pp. 570–573). The difference scores represented by the residuals were then compared between participants from the two grade levels, namely eighth and ninth. Table 1 shows means and standard deviations for pre- and posttest.

The first analyses compared the differences in Belief Identification (BI). The difference in BI between the pre and post data was significant, $t(58) = 5.83$, $p < .001$, d = .75. Participants' BI was higher in the post-intervention (M = 30.58, SD = 3.84) than the pre-intervention (M = 29.20, SD = 3.82). When the difference scores were compared by grade, ninth graders had significantly higher scores than eighth graders: $t(58) = 2.15$, $p = .036$.

This set of analyses was then repeated for Flexible Thinking (FT). Again, the difference between the pre- and posttest scores was significant: $t(58) = 4.60$, $p < .001$,

Table 1. Means and standard deviations of the pre and posttest (n = 60).

		Pretest		Posttest				
Dependent Variables	Dimensions	*M*	*SD*	*M*	*SD*	*t*(58)	*p*	Cohen's *d*
Active Open-Minded Thinking	Belief Identification	29.20	3.82	30.58	3.84	5.83	< .001	.75
	Flexible Thinking	63.60	6.55	65.25	5.82	4.60	< .001	.59
	Dogmatic thinking	36.80	5.97	37.72	4.99	6.41	< .001	.83
	Total	129.60	12.60	133.55	10.30	6.17	< .001	.79
Problem Finding								
	Fluency	7.77	5.09	14.03	9.70	2.00	050	.26
	Originality	4.72	4.31	11.27	9.14	3.23	002	.42

d = .59. Flexible thinking was higher in the post-intervention scores (M = 65.25, SD = 5.82) than the pretest scores (M = 63.60, SD = 6.55). The difference scores varied significantly between eighth and ninth graders: $t(58) = 3.19$, $p = .002$.

Dogmatic Thinking (DT) scores also significantly differed between the pre and posttest scores: $t(58) = 6.41$, $p < .001$, $d = .83$. Posttest scores (M = 37.72, SD = 4.99) were significantly higher than the pretest scores (M = 36.80, SD = 5.97). Again, the difference was higher for ninth graders than the eighth graders: $t(58) = 3.05$, $p = .003$.

When the total scores were analyzed, a significant difference was found between the pre- and posttest scores: $t(58) = 6.17$, $p < .001$, $d = .79$. Post-intervention scores were significantly higher (M = 133.55, SD = 10.30) than pre-intervention scores (M = 129.60, SD = 12.60). The differences between pre- and posttest scores varied by grade. They were higher for ninth graders than eighth graders: $t(58) = 4.99$, $p < .001$.

For fluency, the difference was not significant, $t(58) = 2.00$, $p = .050$, d = .26, and did not differ by grade. However, originality scores were significantly higher in the posttest than the pretest: $t(58) = 3.23$, $p = .002$, $d = .42$. Originality scores almost tripled after the intervention (M = 11.27, SD = 9.14) over the pre-intervention scores, (M = 4.72, SD = 4.31). The difference did not vary by grade: $t(58) = 1.09$, $p = .280$.

Discussion

The results indicated a significant difference due to the enrichment program among the students on the three subscales of the AOT as well as the overall AOT score. Additionally, there was a significant difference between pre- and posttest on PF originality scores, while there was no significant difference in PF fluency scores.

The results suggest that the program succeeded in helping the female participants develop a set of abilities, more specifically, the ability to collect and assess facts and information. Moreover, the program helped participants to: (a) face difficult situations and problems, (b) formulate ill-defined problems, (c) think of more than one way to solve problems, (d) consider varied situations from different angles, and (e) keep in mind multiple choices before making a decision.

The results can be explained in light of the program's designed activities that emphasized the importance of motivation and encouragement to generate knowledge by considering a variety of perspectives. Additionally, the program's enrichment activities focused on helping students organize their knowledge and experiences, so that they might change their system of knowledge processing (Dennis & Vander Wal, 2010; DeRubeis et al., 1990; Fresco et al., 2007). Moreover, the enrichment program helped students become aware of the alternative situations involved in designing robots, to find novel problems, and to demonstrate cognitive flexibility in situations that they might encounter (Bub et al., 2006; Chevalier & Blaye, 2009; Deák, 2003).

The program also affected the aspect of belief determination, which indicates that students' perception of their belief changes in relation to their self-concept. The program helped female students overcome the prevailing norm in Saudi Arabian culture where males are considered more capable and productive than females.

This study is unique because it included PF as a variable of interest for gifted students. It is surprising that PF does not play a more central role in gifted programs as well as in the process of identifying who is gifted. Gifted students need to learn how to find and solve ill-defined problems, which can be called real-world problems. Einstein and Infeld (1938) stressed that the formulation of a problem is often more essential than its solution (p. 92). The results of this study demonstrated that PF plays a major role in the creative process, especially in this enrichment program on robotics where students had the freedom to select a problem for investigation.

This study has some limitations. First, it utilized a one-group pretest-posttest design. Once the criteria were set and the gifted students were selected, it was ethically difficult to create a control group. However, as indicated earlier, this was not the only study that employed a one-group experimental design (e.g., Coxon et al., 2018; Pinasa & Srisook, 2019). Second, our sample consisted of only female participants because of the program design and cultural issues related to the Saudi Arabian culture. A third limitation was the relatively small sample size, which might not adequately represent the population (i.e., gifted females in Saudi Arabia). However, this is not unique to the current study. For example, the Ramli et al. (2011) study consisted of 48 participants, and the Coxon et al. (2018) study consisted of 45 participants. Future research could extend this study with a larger sample size. Another recommendation for future studies is to consider enrichment programs in other STEAM domains, such as mathematics and art. Finally, future studies might look at cultural differences through a cross-cultural study since the current investigation's findings might not be generalizable with regard to other cultures.

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Photo withheld at the request of author

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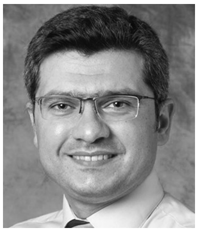

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