

ABSTRACT

HUANG, LIXIAO. Intrinsic Motivation and Self-Determination Theory in Robotics Tournaments. (Under the direction of Dr. Douglas Gillan).

The goal of this study is to examine the extent to which people's motivations in interacting with robots and their relationship with robots are influenced by their basic psychological needs. According to Self-Determination Theory (SDT), satisfaction of people's basic psychological needs for autonomy, competence, and relatedness to others may enhance participants' intrinsic motivation to participate in robotics activities and lead to healthy personal development, while failure to satisfy these needs may undermine intrinsic motivation to do so. Satisfaction of the needs may also contribute to a positive relationship with the robots, which was described as human-robot relatedness in this dissertation, a close connection between humans and robots in which a person has an emotional bond with the robot and perceives the robot as an extended-self and an embodiment that maintains and supports the person's self-concept and self-worth. This dissertation studied a special group of robot users—robotics tournament participants. The results showed that perceived autonomy and perceived competence predicted intrinsic motivation toward robotics activities, identified extrinsic motivation, overall liking of the robot, and relatedness to the robot. Human-robot interaction researchers, designers, and practitioners could use the findings to facilitate peoples' motivations in robotics activities and improve human-robot relationship for mental health and personal development.

Keywords: human-robot relatedness, human-robot relationship, robotics tournament, self-determination theory, motivation

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Intrinsic Motivation and Self-Determination Theory in Robotics Tournaments

by
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DEDICATION

This dissertation is dedicated to my beloved mom, Longmei Shi, for her unconditional love, wisdom, diligence, kindness, and optimistic characteristics that deeply influenced my life.

BIOGRAPHY

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CHAPTER 1

INTRODUCTION

Human–Robot Interaction (HRI) has been a topic of increased popular interest and scientific research in the past decade (e.g., Goodrich & Schultz, 2007; Norman, 2004; Weiss, Bernhaupt, Lankes, & Tscheligi, 2009). A key reason for this increase is the growing demand for service robots—robots that perform useful tasks for humans or equipment, excluding industrial automation applications (Jones & Schmidlin, 2011). Accordingly, robotics education has boomed. Today, millions of youths and adults worldwide spend months each year working on robots in preparation to participate in robotics tournaments (FIRST, 2016). These tournaments can serve as a testing site to study the socio–emotional aspects of HRI, including psychological needs, motivations, and emotions as discussed in the Self-Determination theory (SDT) (Ryan & Deci, 2000b).

SDT addresses people’s motivations toward activities as well as the factors that influence those motivations (Ryan & Deci, 2000a; 2000b). The application of SDT in education suggests that participating in learning activities with intrinsic motivation results in high-level learning and conceptual understanding, enhanced personal development (e.g., self-efficacy), and positive affect (e.g., enjoyment, satisfaction) toward the activities (Deci, Vallerand, Pelletier, & Ryan, 1991). SDT also suggests that intrinsic motivation could be enhanced or undermined depending on whether humans’ basic psychological needs are met. It is important to understand students’ motivations in robotics tournaments and to shape social-contextual factors to facilitate their intrinsic motivation. However, little research has

explored people's motivations in robotics tournaments using SDT and factors that influence their motivations.

In addition to the importance of motivations in human–robot interaction, people's relationships with the materialized products of these robotics activities are also important. A materialized product is a concrete object generated through robotics activities or an agent that facilitates the activities. For example, a tournament robot is a materialized creation generated through the robot-building activities; a math teaching robot, NAO, is an agent that facilitates interactions and math-learning activities. By contrast, activities such as bouldering or swimming do not produce materialized products.

To use robots to improve humans' quality of life and personal development, HRI researchers need to not only enhance humans' intrinsic motivation in interactions with robots, but also promote positive human–robot relationships. The present study applied SDT as a framework to identify the social-contextual factors and motivations in humans' interactions with robots at robotics tournaments. The research investigated (a) people's basic psychological needs, intrinsic motivation, and self-regulated extrinsic motivations in robotics tournaments, (b) humans' relationships with the robots, and (c) the connection between motivations in robotics activities and human–robot relationships.

Self-Determination Theory

Self-Determination Theory (SDT) (Ryan & Deci, 2000a; 2000b) emphasizes the significant relationship between people's intrinsic motivation in their activities and their people's mental health and personal development. The theory stated that people have three innate psychological needs that drive their behaviors: the need for autonomy, the need for

competence, and the need for relatedness [to humans] (Ryan & Deci, 2000b, p. 68). When social–contextual factors satisfy these needs, a person has enhanced intrinsic motivation toward the activities, and can be expected later on to have healthy personal development and improved well-being (Ryan & Deci, 2000b). Conversely, failure to satisfy these needs will undermine the person’s intrinsic motivation and, in extreme cases, even leads to psychopathology—impairments of autonomy that cause the failure of self-development and personality integration (Ryan, Deci, & Grolnick, 1995; Ryan & Deci, 2000b). A robotics education practitioner in China wrote in a reflection article that many mentors in robotics tournaments emphasized awards so much that they created the advanced robots for students to simply imitate. This lack of support for autonomy hindered students’ sense of competence and positive relatedness to the mentors, which undermined intrinsic motivation in learning robotics.

The need for autonomy, or originally termed as the need for self-determination (Deci, 1975), refers to the need to exercise control over one’s actions, reflect the core sense of self and the free choices of the self, and be a causal agent in one’s own life (Ryan & Deci, 2000a). The self is both the agent that integrates and the structure to which new functions, values, and propensities are integrated (Ryan, 1991). The actions are self-regulated and stem from the core organization, which makes the experience significant to the self (Ryan, 1993). Intrinsically motivated behaviors come from the self and are fully endorsed by the self (Deci, Vallerand, Pelletier, & Ryan, 1991). In other words, the need for autonomy reflects the self-concept—a person’s identity and preferences.

The concept of competence in SDT is equivalent to Bandura's (1977; 1989) concept of self-efficacy (Ryan & Deci, 2000b), which also relates to self-worth. Competence refers to accumulated satisfaction in exercising and expanding one's capabilities when interacting with one's environments (White, 1959). The need for competence is the need to experience mastery and affect one's outcomes and surroundings (Ryan & Deci, 2000a). People may fulfill the need for competence when they overcome optimal challenges—challenges with an appropriate level of difficulty (Deci, 1975). If a challenge is too difficult or too easy for a person to solve, that person might feel frustrated or bored, and thus not be able to gain a sense of competence (Csikszentmihalyi, 1975; Danner & Lonky, 1981). However, the sense of competence alone does not enhance intrinsic motivation. Only if the competence is self-determined (i.e., initiated by personal choices) will it enhance intrinsic motivation (Deci et al., 1991). Positive feedback results in higher intrinsic motivation than no feedback (Deci, 1971). Positive outcomes embedded in the tasks and having control over the positive outcomes leads to even higher intrinsic motivation than positive feedback from other people (Russell, Studstill, & Grant, 1979).

The need for relatedness is the need to feel interpersonally connected with others (e.g., parental involvement and peer acceptance), especially with those who provide autonomy support for individuals to engage in activities (Deci et al., 1991; Ryan & Deci, 2000a; Grolnick & Ryan, 1989). Two indexes of relatedness to a human are a sense of caring for and a sense of connectedness to the human. The indexes of relatedness are closely related to the indexes of autonomy support—in the case of parents, this means a sense of parents' taking their children's perspectives, offering choices, and using minimal controls

(Ryan, Deci, & Grolnick, 1995). Caring parents normally support children's need for autonomy. The need for relatedness overlaps with Bowlby's (1969/1982) concept of infant-mother attachment (Ryan, Deci, & Grolnick, 1995, p.639). When caregivers are available and sensitive to fulfill infants' needs, those infants tend to have a secure attachment toward their caregivers and are more willing to explore and experiment in caregivers' presence than if they do not have a secure attachment. In Bowlby's (1969/1982) and Ainsworth's (1978) attachment research, fulfilling infants' needs means the caregivers not only provide autonomy support but also provide help for infants to resolve obstacles and build a sense of competence. Conversely, when parents are involved in a commanding way that hinders the satisfaction of need for autonomy and competence, then the need for relatedness could contribute to youths' developing extrinsic motivation (i.e., doing things for an outcome that is outside of the activity itself and is not harmonious with the sense of self) or even amotivation (i.e., no motivation). Both amotivation and extrinsic motivation hinder conceptual learning and personal growth (Deci & Ryan, 1985). Denying children's desire for interpersonal involvement can cause them to lose intrinsic motivation in their activities (Anderson, Manoogian, & Reznick, 1976). Therefore, the capabilities of people in the environment to provide support for autonomy and competence determine whether a person's intrinsic motivation toward an activity is enhanced.

Intrinsic motivation is an impetus or inspiration to act based on internal drives or needs (Ryan & Deci, 2000b) and it "reflects the human propensity to learn and assimilate" (Ryan & Deci, 2000b, p. 54). The pleasure, satisfaction, enjoyment, and fun that are derived from the participating in experiences all indicate and serve as a measure of intrinsic

motivation (Deci, Vallerand, Pelletier, & Ryan, 1991). Intrinsic motivation has three sub-dimensions of activities through which people gain pleasure and satisfaction (Vallerand et al., 1992, 1993). Intrinsic motivation to know is expressed through learning, exploring, or understanding new things. Intrinsic motivation toward accomplishments is expressed through accomplishing or creating things. Intrinsic motivation to experience stimulation is expressed through experiencing stimulating sensations, such as sensory pleasure and aesthetic experiences, as well as fun and excitement (Vallerand et al., 1992, 1993). People who are intrinsically motivated to participate in learning activities experience higher levels of conceptual learning and positive emotions (Deci, Vallerand, Pelletier, & Ryan, 1991), and are more persistent in handling difficulties than those who are not intrinsically motivated. The resulting positive cognitive processes are fundamental to personal development and mental health (Ryan & Deci, 2000b).

The research reviewed above on autonomy, competence, relatedness to humans, and intrinsic motivation led to the first hypothesis motivating this research.

Hypothesis 1a: The higher the students rate perceived autonomy in their robotics tournament work, the higher they will rate their intrinsic motivation toward robotics activities.

Hypothesis 1b: The higher the students rate perceived competence in the robotics tournament, the higher they will rate their intrinsic motivation toward robotics activities.

Hypothesis 1c: The higher the students rate perceived relatedness to humans (mentors, team members, and/or audiences) pertaining to robotics tournaments, the higher they will rate their intrinsic motivation toward robotics activities.

Extrinsic motivations also play a key role in education when some activities are not inherently interesting but important for personal development, such as some students do homework to gain praise from teachers but not necessarily enjoy the homework. Extrinsic motivation drives people to participate in activities not for the enjoyment of the activities but for separate outcomes beyond the activities (Deci, Vallerand, Pelletier, & Ryan, 1991).

Deci and Ryan (1985) identified four types of extrinsic motivations that are associated with an increased degree of self-determination: (1) external motivation—having an external locus of control for the consequence (e.g., rule enforcement by teachers, in which teachers are an external source of control); (2) introjected motivation—taking in but not accepting a regulation as one's desired initiation (e.g., doing a task to avoid guilt or to fulfill a promise, in which the guilt or promise is beyond the task itself); (3) identified motivation—identifying the value of the activities to achieve something beyond the activity and willingly participating in the activities with a sense of choice, but not because the activity itself is interesting (e.g., learning math in order to become a successful robotics scientist, in which the task is learning math, but the goal of becoming a robotics scientist is beyond the task); and (4) integrated motivation—integrating one's interest in an activity into the coherent sense of self, personal values, needs, and identities, but having unresolved conflict with the rest of the sense of self (e.g., being interested in robotics but experiencing conflicts with the normal school schedule, in which, there is interest in the task, robotics, but the schedule conflicts caused unease in the mind; once the conflict is resolved by setting a practical priority, the motivation in robotics may become intrinsic motivation).

These four extrinsic motivations plus intrinsic motivation differ in the source of initiation and locus of control. External motivation has an external source of initiation and external locus of control. Introjected motivation has an external source of initiation but has somewhat internal locus of control that is different from the task. Identified motivation has internal source of initiation and has an internal locus of control over the task, but it is about the value of the task, rather than the enjoyment of the task. The integrated motivation has internal initiation and internal locus of control of the task, and has interest in one task but having obstacles to fully engage in the activity. Intrinsic motivation has full enjoyment of doing the task (see Figure 1 for an illustration of the continuum). Introjected, identified, and integrated motivation all have some level of self-determination or self-regulation (Ryan & Connell, 1989), but introjected was somewhat external according to Ryan and Deci's motivation continuum (2000b). Therefore, only identified and integrated motivation is categorized as self-regulated extrinsic motivation. In addition, identified and integrated motivation has internal locus of causality that are relevant to the tasks itself, while external and introjected motivation is not about the task itself. Due to the fact that identified motivation involves the awareness of the importance of the task and the fact that integrated motivation involves some level of intrinsic motivation, these two types of extrinsic motivations are considered critical to personal growth too.

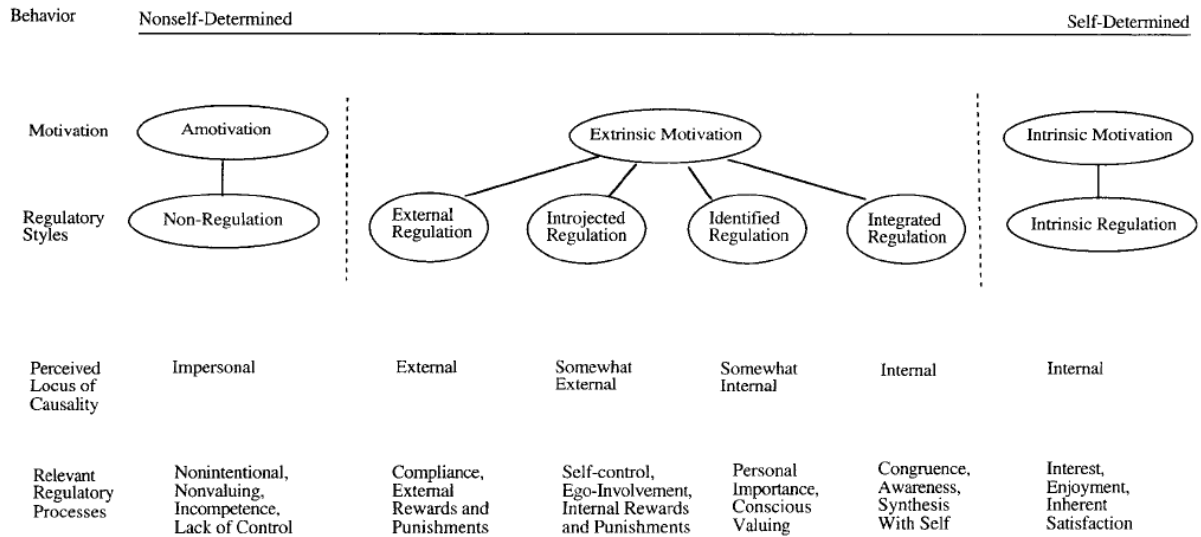


Figure 1. The self-determination continuum showing types of motivation with their regulatory styles, loci of control, and corresponding processes (credit: Ryan & Deci, 2000b).

Due to the significant relationship between intrinsic motivation and healthy personal development, the more internalized the motivation a person has toward an activity, the more enjoyment and satisfaction the person feels from the activity, and thus, will have better development by participating in the activity (Ryan & Deci, 2000b). The internalization regulation enables a person to gain the sense of control to reflect the self (i.e., self-determined) when participating in activities (Ryan & Connell, 1989), which contributes to personality integration and personal development, and eventually a person's well-being (Ryan & Deci, 2000b).

Since self-regulated extrinsic motivations share some level of self-control with intrinsic motivation, it is reasonable to propose hypothesis 2 concerning the relationships between the basic psychological needs and self-regulated extrinsic motivations.

Hypothesis 2a: The higher the students rate perceived autonomy in their robotics tournament work, the higher they will rate their self-regulated extrinsic motivation toward robotics activities.

Hypothesis 2b: The higher the students rate perceived competence in the robotics tournament, the higher they will rate their self-regulated extrinsic motivation toward robotics activities.

Hypothesis 2c: The higher the students rate perceived relatedness to humans (mentors, team members, and/or audiences) pertaining to robotics tournaments, the higher they will rate their self-regulated extrinsic motivation toward robotics activities.

To determine whether a person has intrinsic or extrinsic motivation in performing a task, asking the reasons for acting has been widely used to measure different types of motivations (Ryan & Connell, 1989; Vallerand et al., 1989; Vallerand et al., 1992, 1993). The recognized and endorsed reasons represent a person's intentions behind their behaviors, and they have conceptual significance in intrapersonal perception (Buss, 1978; Ryan & Connell, 1989). Researchers (e.g., Ryan & Connell, 1989) interviewed participants to get a full list of reasons for a few interested behaviors, categorized the reasons under the four different types of motivations (i.e., the external, the introjected, the identified, and the intrinsic motivation, not including integrated motivation due to its subtle difference from intrinsic motivation), and asked the participants to rate each reason on a 2-point scale (sort of true, really true) (Harter, 1981) or on a 4-point scale (very true, sort of true, not very true, and not at all true) (Ryan & Connell, 1989).

In addition to the three basic psychological needs, SDT also found the positive correlations between a person's effort and time input with three nonexternal motivations – introjected, identified, and intrinsic motivation (Ryan & Connell, 1989). The effort was measured using one question “I try hard to do well in school” on a 4-point scale as described in above (Ryan & Connell, 1989). The effort rating is likely to be a behavioral result of the self-regulated motivation. Meanwhile, consumer behavior research found that customers valued self-designed products because of the efforts they invested and the enjoyment of the design process they experienced (Franke & Schreier, 2010; Franke, Schreier, & Kaiser, 2010). In other words, effort and time input is not the discerning criterion for intrinsic motivation or extrinsic motivation, instead, the discerning criterion is enjoyment and satisfaction in the activity itself, because people may invest effort and time on things they are either intrinsically motivated to do, or extrinsically motivated to do. This review of research leads to the third hypothesis:

Hypothesis 3a: The higher the students rate the effort and time input, the higher they will rate their intrinsic motivation toward the robotics activities.

Hypothesis 3b: The higher the students rate the effort and time input, the higher they will rate their self-regulated extrinsic motivation toward the robotics activities.

Hypothesis 3c: The higher the students rate the effort and time input, the higher they will rate their relatedness to their robots, which will be introduced in the next section.

Humans' Relatedness to Robots

Human–robot relatedness is a new concept to address a relationship between humans and robots after long-term interactions. Self-Determination Theory (SDT) primarily deals

with people's motivations to perform specific activities but does not address the relationship between humans and the materialized creations of the activities, if any. Consumer behavior research (Atakan, Bagozzi, & Yoon, 2014) found that participation in the process of creating products leads to consumers' enhanced evaluation of the self-made products, especially with positive production experiences, because positive production experiences shorten the psychological distance between the self and the product and strengthen the maker's identification with the product (Atakan et al., 2014). Research found that a person tends to extend his sense of self into the things he controls, creates, or personalizes (Belk, 1988). For example, people projected self-extension into the robots they use (Groom, Takayama, Ochi, & Nass, 2009). The building process increased builders' affection for their creations (Norton, Mochon, & Ariely, 2012). More specifically, self-integration—the perceived link between the self and the outcome—mediated the effect of self-production on outcome evaluation (Troye & Supphellen, 2012).

As a materialized creation resulting from people's robot-building activities, a tournament robot may reflect the robot builders' free choices, accomplishment, and relationships with other people on the team. Following the Three-Factor Theory of anthropomorphism (Epley et al., 2007), there are three factors that may lead people to anthropomorphize the robots and assign human roles to them: the robots' resemblance to humans in function or form, humans' desire to explain robot behaviors, and humans' desire to socially connect to others. Research indicated that humans interacted with computers, TVs, and other technologies the way they interacted with other humans (Reeves & Nass, 1996). When people interacted with autonomous robots or robots tele-operated by other

humans, people responded to the robots the way they responded to other humans (Fong, Nourbakhsh, & Dautenhahn, 2003). This research suggests that it is possible for robot builders to develop a sense of relatedness and positive emotions toward the robots they build. Positive emotions include interest and love, and they can enhance people's physical resources, intellectual resources, and social resources (Fredrickson, 1998), and optimize health and well-being (Fredrickson, 2000). Other research studied negative emotions and attitudes toward robots (e.g., Syrdal, Dautenhahn, Koay, & Waters, 2009), but these negative responses are not the focus of this study.

Research in HRI has described the relationship between humans and robots as emotional attachment. Coeckelbergh (2011) predicted that children would develop attachment to robots after long-term interactions. Modern researchers have studied humans' attachment to robot dogs (Fried, Kahn, & Hagman, 2003; Weiss, Wurhofer, & Tscheligi, 2009), robot vacuum machines (Sung, Grinter, Christensen, & Guo, 2008; Sung, Guo, Grinter, & Christensen, 2007), and military robots (Ackerman, 2013; Barber, 2013; Carpenter, 2013; Chayka, 2014; Garber, 2013).

A commonly used definition of human-robot attachment comes from Norman's (2004) book, *Emotional Design*. In the book, Norman discussed humans' attachment to products and the association between a person and a thing. He proposed three levels of object appreciation: visceral (i.e., immediate attraction to an object based on its appearance at first glance), behavioral (i.e., love for a product because of its function and usability, which is based on the quality of interaction experiences), and reflective (i.e., strong emotional response to an object that has special meaning to the individual). Although Norman did not

explicitly define emotional attachment, he implied that strong positive emotions elicited by any of these three levels of object appreciation, or by some combination of them, indicate emotional attachment to the object.

In the example of humans' attachment to a robotic dog, AIBO, researchers conducted a free exploration of children's and adults' initial reactions to AIBO at a shopping mall (Weiss, Wurhofer, & Tscheligi, 2009). Weiss et al. found that children demonstrated positive emotions toward all three appreciation levels of the robot: they were attracted to the robot dog when they first saw it (visceral), they played with it for a period of time (behavioral), and they expressed the wish to bring it home as a companion (reflective). Based on these findings, Weiss et al. concluded that the children had rapidly developed emotional attachment to the robots.

However, the concept of attachment has a restricted definition in developmental psychology. Bowlby's foundational attachment theory held that the infants become attached to their mothers based on four defining characteristics: (a) the infants seek proximity to their mothers, (b) the mothers provide comfort to their infants when the infants are in distress, (c) the infants were more willing to explore the environment when their mothers are around, and (d) the infants display strong and lasting anxiety when separated from their mothers. Bowlby (1982) stated that the infant-mother attachment is a safety-regulated relationship that helps the infants survive, and therefore, other lower-stake relationships that do not abide by this rule (e.g., children seeking playmates) are not defined as attachment. Bowlby's attachment theory has been so influential in developmental psychology that applying attachment to humans-nonhumans has not been accepted yet (Bretheton, 1992).

Because the concept of attachment has not been justified as applicable to human–nonhuman relationships, the present study does not describe humans’ positive responses to robots in terms of emotional attachment, but rather uses the term relatedness to robots. Integrating previous research in human emotional responses to robots (Huang & Gillan, 2014; Huang, Varnado, & Gillan, 2013) and research in consumer–product relationship research (Ball & Tasaki, 1992), the concept of human–robot relatedness indicates a relationship between humans and robots in which the human has an emotional bond toward the robot, and perceives the robot as an extended self and an embodiment of the significant others, things, and memories to maintain and support their self-concept and self-worth. The more specific meanings are as following: (a) an extended self, meaning that the robot reflects a person’s preferences, creativity, capabilities, and goals, which is projected as who the person is, the self-concept; (b) an embodiment of feelings for other people, things, memories, and activities, meaning that the robot embodies the connections with other humans and the relevant experiences that have special meanings to the person; and (c) an emotional bond, meaning that the person experiences a mixture of positive emotions toward the robot, such as caring about the robot, feeling close to or attached to the robot, and bonding with the robot. An extended self differs from an embodiment because an extended self mainly focus on the self-concept and embodiment includes other people, things, and activities. The literature review of this section leads to the fourth hypothesis that underlies this research.

Hypothesis 4a: the higher the students rate their perceived autonomy, the higher they will rate their relatedness to the robot.

Hypothesis 4b: the higher the students rate perceived competence, the higher they will rate their relatedness to the robot.

Hypothesis 4c: the higher the students rate the perceived relatedness to humans (mentors, team members, and/or audiences), the higher they will rate their relatedness to the robot.

The fifth hypothesis is based on the fact that motivations and emotions are closely connected. Self-regulated extrinsic motivation, intrinsic motivation, and relatedness to the robot all share some level of emotions.

Hypothesis 5a: the students' intrinsic motivation to engage in robotics activities is positively correlated with their relatedness to the robot.

Hypothesis 5b: the students' self-regulated extrinsic motivation in robotics activities is positively correlated with their relatedness to the robot.

Among the positive emotions toward the robot, overall liking of the robot is part of the relationship between a human and a robot. Since this question was used in previous studies (Huang & Gillan, 2014), it seemed an effective question to repeat in this study, which led to the sixth hypothesis:

Hypothesis 6a: The higher students rate perceived autonomy in their robotics tournament work, the higher they will rate their liking of the robot.

Hypothesis 6b: The higher students rate perceived competence in the robotics tournament, the higher they will rate their liking of the robot.

Hypothesis 6c: The higher students rate perceived relatedness to humans (mentors, team members, and/or audiences) pertaining to robotics tournaments, the higher they will rate their liking of the robot.

The Present Study

Self-Determination Theory identified three basic psychological needs that stem from the self and drive other behaviors: the need for autonomy, the need for competence, and the need for relatedness (Ryan & Deci, 2000b). In this study, it was predicted that high ratings on the satisfaction of these three needs would enhance participants' intrinsic motivation toward robotics activities, and the enhanced intrinsic motivation would result in positive emotions toward a durable end product of the activity—in the case of robotics tournaments, the robots. Therefore, the basic psychological needs would also predict participants' relatedness to their robots. Not much research has been found to examine the relationships between the satisfaction of the psychological needs and self-regulated extrinsic motivation, so it was tested in the research as an exploration. Three main research questions are shown in Figure 2: (a) What are the relationships among the three basic psychological needs and the tournament robot builders' motivation towards robotics activities? (b) What are the relationships among the three basic psychological needs and the robot builders' relationship with their robots (liking and human–robot relatedness)? (c) What is the relationship between the motivation in robotics activities and humans' relatedness to the robot? All variables and hypotheses were presented in Figure 3.

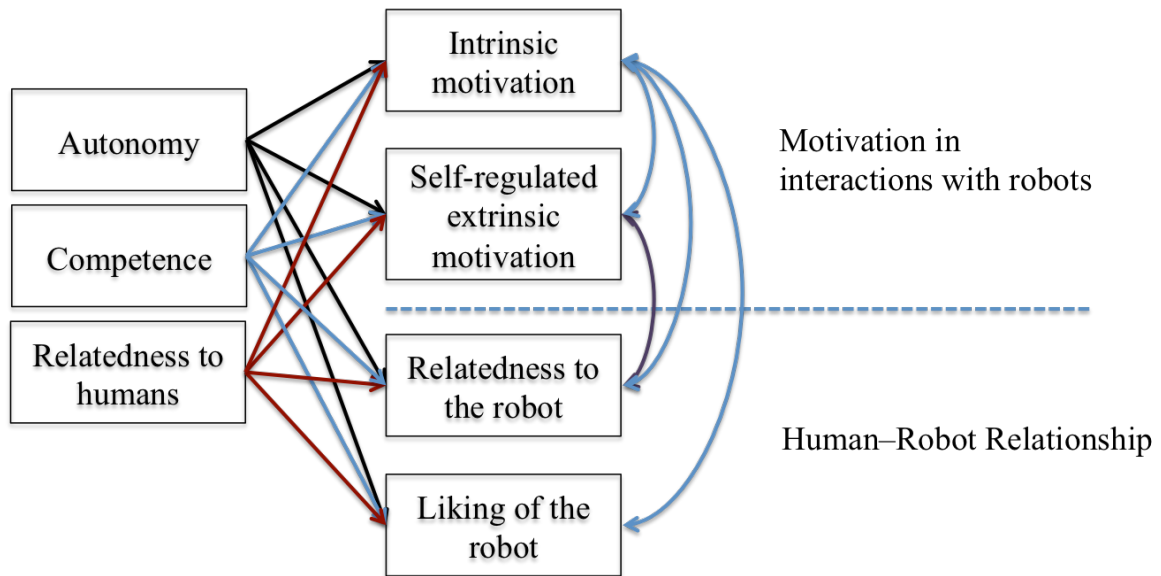


Figure 2. Main research framework.

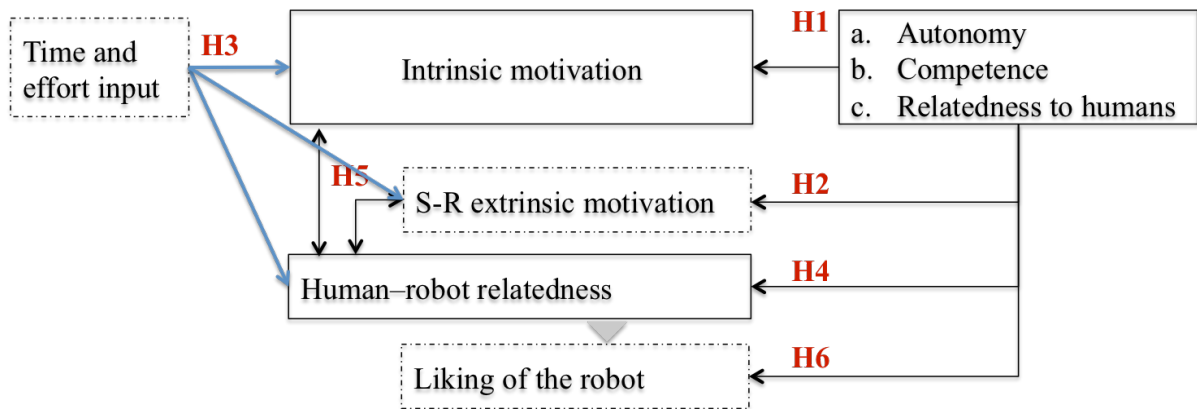


Figure 3. A summary of hypotheses.

CHAPTER 2

METHOD

Participants

This study collected data from 147 youth participants in total between April and June 2016 from FIRST Tech Challenge (FTC), FIRST Robotics Competition (FRC), Amazon Picking Challenge, Skills USA robotics competition, SoutheastCon competition, and individual robotics hobbyists. The final data included 122 youth participants from FTC and FRC tournaments because these tournaments had the largest sample size and less diversity in participants' ages and game settings. Participants' ages ranged from 14 to 18 years ($M = 16.06$, $SD = 1.13$, $N = 122$; $male = 74$). Table 1 shows the demographic information of age, gender, education level, and robotics experiences. 121 students participated in this year's tournaments except that one student did not participate in this year's tournament but had experiences with previous tournaments. It was the first time tournament for 37 of them.

Concerning robotics tournament experiences, if participants had current-year tournament experiences, then they were asked to use the current-year robot to answer the questions for the rest of the survey. There were two reasons for doing this: (a) the participants' memory about the current-year robots was likely to be most accurate; and (b) reflecting on the same year tournament robot would make it possible to compare different tournaments in future studies.

Table 1 Demographic Information of Participants

| | Frequency | Percent |
|---|-----------|---------|
| Gender | | |
| Male | 74 | 60.7 |
| Female | 46 | 37.7 |
| Other | 2 | 1.6 |
| Education | | |
| 8th grade | 3 | 2.5 |
| 9th grade | 28 | 23.0 |
| 10th grade | 34 | 27.9 |
| 11th grade | 25 | 20.5 |
| 12th grade | 23 | 18.9 |
| Some college/currently enrolled | 7 | 5.7 |
| Other level | 2 | 1.6 |
| Tournament Experiences | | |
| Current and first-year tournament participant | 37 | 25.2 |
| Current and multiple year tournament participants | 84 | 73.0 |
| Previous year tournament participant | 1 | 0.8 |
| Total | 122 | 100 |

Robotics Tournaments

This study mainly included participants from FIRST Tech Challenge (FTC) and FIRST Robotics Competition (FRC). With limited resources and strict rules, FTC teams consist of 10 or more members (grades 7–12; ages 12–18) who worked for at least six weeks intensively with volunteering mentors to design, build, and program a robot to compete against other robot teams. They also needed to conduct fundraising activities and community outreach. FRC teams have 25 or more members (grades 9–12; ages 14–18), and their tasks are to build more challenging robots than FTC teams. For both tournaments, participants are eligible to apply for more than \$25 million dollars of college scholarships. Each team receives a kickoff kit made up of donated items and components with limited instructions.

Based on each year's challenges, students work with mentors to design, build, and program robots that weigh up to 120 pounds (see Figure 4 and Figure 5).

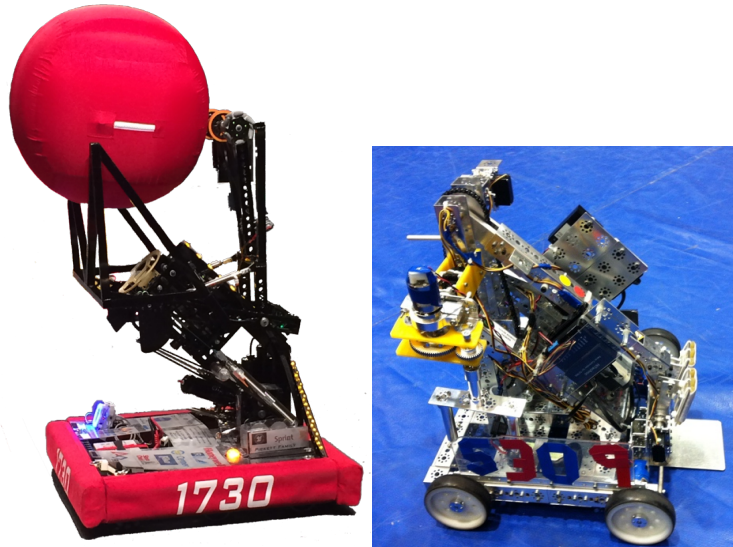


Figure 4. An example of an FRC robot 2014/2015 (left; photo credit: frcbayouregional.com), an example of an FTC robot 2014/2015 (right; photo credit: Lixiao Huang).



Figure 5. An example of an FTC robot kit for 2014/2015 PushBot Challenge (photo credit: unknown).

Measures

The first question in Human–Robot relatedness scale, “How much do you like the robot?” was asked separately, using a 101-point bar scale with five anchored labels (0 = None at all; 25 = A little, 50 = A moderate amount, 75 = A lot, 100 = A great deal). All other quantitative items in this dissertation used a 21-point bar-scale, from -10 to 10 (-10 = Strongly disagree, -7 = Disagree, -3 = Somewhat Disagree, 0 = Neither Agree nor Disagree; 3 = Somewhat Agree, 7 = Agree, 10 = Strongly Agree). The words in parentheses at the end of each survey item below are short names for these items used in the results section.

Perceived autonomy. This dimension included two items from Ryan and Deci’s (2003) intrinsic motivation inventory (IMI). A Cronbach’s Alpha value of .63 indicated a relatively low reliability ($N = 109$), but the reliability is acceptable due to the small number of items in this scale (Field, 2009). The two items had a significant correlation ($r = .48, p < .01, N = 122$).

1. I worked on the robot because I wanted to. (Wanting to do)
2. I worked on the robot because I didn’t really have a choice about doing it. (Reverse scored) (Having choices)

Perceived competence. This dimension included two items from Ryan and Deci’s (2003) Intrinsic Motivation Inventory (IMI). The remaining 3 items were developed for the current study. The scale had a good reliability, Cronbach’s $\alpha = .81$ ($N = 101$, listwise deletion) (Field, 2009).

1. After working on robotics for a while, I felt pretty competent (Ryan & Deci, 2003).
(Feeling competent)

2. I am satisfied with my overall performance on the robot (Ryan & Deci, 2003).
(Satisfying performance)
3. The robot reflects my achievements. (Achievement)
4. The robot reflects my knowledge and skills in robotics. (Robotics knowledge and skills)
5. The robot reflects my knowledge and skills in project management. (Project management)

Perceived relatedness to humans. This study measured perceived relatedness through the following three items—support from team members, support from audiences, and support from outside friends. A Cronbach’s Alpha value of .55 ($N = 100$) indicated a relatively low reliability (Field, 2009).

1. I like our robotics team’s teamwork. (Teamwork)
2. I like to participate in the promotional outreach activities related to the robot.
(Promoting outreach)
3. I like to talk about the robot to my friends and other people who are interested.
(Talking to others)

In addition, the study used an essay question (“Do you think the other team members working on the robot competition made you like the robot more or less? Please explain.”) to elicit in-depth reasons for the team members’ influence on participants’ liking of the robot.

Intrinsic motivation. Intrinsic motivation concerns humans’ enjoyment of and interest in activities. Similar studies have used the statements “I enjoy doing my classwork” and “I like doing my homework” (Ryan & Connell, 1989). Deci (1975) stated that behaviors

that are done out of interest and do not require extrinsic reward or reinforcement, such as play and exploration, are manifestations of intrinsic motivation and are rewarding in their own right. The item “feeling rewarding about solving difficult problems” was used because feeling a sense of reward indicates satisfaction in the activity itself. A Cronbach’s Alpha value of .50 indicated a relatively low reliability (Field, 2009).

1. Building robots is fun. (Fun Building)
2. I like playing with the robot. (Liking playing)
3. I found solving difficult problems on the robot was extra rewarding. (Rewarding problem-solving)

Self-regulated extrinsic motivation (Non-external extrinsic motivation). People with self-regulated extrinsic motivation take in the value of the activities but aim for the outcomes that are outside of the activity itself (Deci et al., 1991). They are self-regulated because these extrinsic motivations all have some level of autonomous regulation. The identified motivation relates to the recognized value of the activity, such as learning. The goal contents could also be extrinsically oriented or intrinsically oriented (Vansteenkiste, Lens, & Deci, 2006). Since learning, the future self, and career goals are self-identified values but not the activity itself, they are considered self-regulated extrinsic motivation. A Cronbach’s Alpha value of .82 (N = 104) indicated a good reliability (Field, 2009).

1. Working on the robot may help me become who I want to be. (Future self)
2. I found the robot helpful in learning science and technology. (Learning)
3. The robot reflects my career goals. (Career goals)

Perceived relatedness to the robot. The perceived relatedness to the robot questionnaire consisted of 13 scale items. This survey was a revised version of a previous survey about emotional responses to robots (Huang & Gillan, 2014), consisting of two dimensions in the relatedness to the robot—positive responses in general and negative responses when the robot is damaged or separated. A Cronbach's Alpha value of .90 ($N = 56$) indicated a good reliability (Field, 2009). The first question, “How much do you like the robot?” used a 101-point bar scale. The rest of the items used a 21-point bar scale. To include liking of the robot in the relatedness to the robot scale, the overall liking was fit to a 10-point scale by dividing by 10. Disliking of the robot is not the focus of this study.

1. How much do you like the robot? (Liking)
2. I am passionate about the robot. (Feeling passionate)
3. I care about the robot. (Caring)
4. I have no feelings for the robot. (R) (Lack of feelings)
5. I would feel sad if the robot could no longer function. (Sadness_no function)
6. I feel that I am attached to the robot. (Attachment)
7. The robot means a lot to me. (Significance)
8. I feel good being with the robot. (Feeling good)
9. I feel close to the robot. (Closeness)
10. If I had to dismantle the robot, I would feel sad. (Sadness_dismantle)
11. I would feel hurt if the robot got scratched or broken. (Hurt_scratch)
12. I would feel bad if I could no longer see the robot. (Feeling bad_no longer see)

13. If someone praised the robot, I would feel somewhat praised myself. (Feeling praised) (Schiffenstein & Zwartcruis-Pelgrim, 2008)

Reasons for liking and motivation types. An essay question asked people to explain the reasons for their rating of liking after they rated the scale question (“How much do you like the robot on a scale of 0–100?”). Asking about the reasons for actions, instead of reasons for liking, may have elicited responses that fell either under intrinsic motivation or different types of extrinsic motivation. By contrast, asking about the reasons for liking primed people to give reasons related to intrinsic motivation. Therefore, the data analysis coded the reasons within intrinsic motivation rather than crossing different motivations. As a reference for development of the code categories, researchers identified three types of intrinsic motivations—intrinsic motivation to know, to accomplish, and to experience stimulation (Vallerand et al., 1992, 1993).

Effort and time input. The measure of effort used one single question: “I feel I put a lot of effort into the robot.”

Quantitative data management. The survey used a 101-point bar scale and a 21-point bar scale, which might not be as common as the 5- or 7-point likert scales. Without using the forced-response option, some participants might have skipped some questions due to unfamiliarity or reluctance to answer. The final data analysis treated the default values (e.g., 0 on the 101-point liking of the robot question and -10 on the 21-point bar scale) as missing data because more than thirty participants who rated 0 on liking explained the reasons why they liked the robot a lot. In other words, the default value was an omitted response.

Involvement levels. The survey asked participants to answer, “Your role(s) on the

team and responsibilities on the robot (choose all that apply)”, expecting them to check the types of tasks they had done on the robotics team: (1) Directly involved: mechanical, electrical, programming, CAD, and driving the robot; (2) Indirectly involved: strategy, mentor, cheerleading, media, and marketing. The option of “other” allowed participants to list tasks that were not provided on the survey.

Procedure

The researcher visited robotic tournaments in a southeastern state in the United States from March to April 2016 to introduce the research survey to robotics team members, coaches, and mentors in person. The researcher also contacted event coordinators who knew other mentors. Then, the mentors helped distribute the survey via email to their students who had participated in robotics tournaments or robotics classes. All participants who filled out the entire survey were offered three types of benefits: (a) receiving a copy of the research paper when it was done; (b) entering the drawing for one of five \$50 Amazon gift cards or check donations to their robotics team; and (c) keeping in contact for future discussions or collaborations related to Human–Robot Interaction (HRI) research, Robotics Education, and Human Factors in Robot Design, or general questions about college and graduate school that the researcher might be able to help with.

Qualitative Datasets and Coding

This study included three qualitative datasets of text responses to the essay questions: (1) reasons for liking the robot, (2) reasons for not liking the robot, and (3) whether team members influenced the participant’s liking of the robot.

The analysis of the text corresponding to the essay questions used Geisler’s (2004)

verbal data analysis method, from the segmentation of the raw data to the final visualizations. All sentences were broken down to T-unit level—a minimal terminable unit (Hunt, 1965)—for further coding (see Table 2 for an example of one person’s response). The coding process used Saldana’s (2009) method to develop the codebook from the raw postings. This was a bottom-up process, specifically accustomed to the current scenario. The codebook included coding categories, definitions, and examples (see Tables 3, 4, and 5). The author and an objective second coder (who was unfamiliar with the research) independently coded the first 100 minimal meaning units according to the codebook. Then, the first author checked the disputed coding items to make adjustments to the codebook. After both coders had recoded another 100 units to reach with a simple agreement of 80% inter-rater reliability and a *Kappa value of .70*, the researcher then finished the coding for the rest of the dataset.

Table 2 An Example of T-units of One Person’s Response and Coding Category

| T-units | Coding Category |
|--|--|
| • The process of designing, constructing, and coding the robot | Interest in the direct building activities |
| • made me really like it. | Positive connection with the robot |
| • As well, the robot performed all the original intended goals | Positive function |
| • (though, we had difficulty making it achieve later goals). | Negative comments about the robot |

Table 3 The Codebook of Reasons Students Liked Their Robots

| Dimension | Category | Definition | Examples |
|----------------|---|--|---|
| Robot features | Design | Coding as positive comments about the design of the robot | <ul style="list-style-type: none"> • “I really like the design of the robot.” • “It has a great, modular design” • “...and good code to back it up.” • Keywords used: good design, good code, simple design, adding a suspension to the robot, one of the most successful designs, neat design, decent design |
| | Form | Coding as comments about the robot form and appearance | <ul style="list-style-type: none"> • “He had a vision system that looked like neon green eyes,” • “(I am very pleased) with the way it looks.” • Keywords used: cool, the vision system looked like neon green eyes, a very nice look, has style and character, personality |
| | Function | Coding as positive statements about the tournament results and functions of the robot | <ul style="list-style-type: none"> • “...and it is the only FTC robot in our club history to make it to either Super Regionals or Worlds” • “I like that our robot can perform many of the required functions,” • “...which worked out great.” • Keywords used: function well, work most of time, work well, consistent, performed all the original intended goals), perform well, get the job done, served us well, able to succeed in almost all parts of the challenge, does a great job competing, functional, competitive, robust, perform wonderfully |
| | Overall positive comments about the robot | Coding as overall positive statements of the robot without mentioning specific aspects | <ul style="list-style-type: none"> • “I think it is quite a beautiful thing.” • “...our finished robot, it felt truly breathtaking and powerful” • Keywords used: awe-inspiring, mind-blowing, a beautiful thing, breathtaking, powerful, super modular, great success, one of the most complex robots we've ever built, monster on the field, our best robot ever, most successful robot, good robot, great robot, really great bot, really awesome |

Table 3 Continued

| Dimension | Category | Definition | Examples |
|--|--|---|---|
| Robot features | Overall negative comments about the robot | Coding as negative comments about the robot about its form, function and design | <ul style="list-style-type: none"> • "...turning to be against our favor in worlds (the world championship)." • "...even if it was not the prettiest" • "The shooting didn't work entirely" • Keywords used: sub-par design, unnecessarily complicated, wasn't too great, not prettiest, not great robot being bulky and tall, malfunctions, unstable, finicky, poor quality, against our favor in worlds, never worked how we wanted it to, did not work consistently, would have preferred it to be able to climb, ups and downs to our design, breaking parts, not as successful as hoped, wasn't perfect, disapprove its design |
| Intrinsic Motivation toward activities | Interest in the direct building activities | Coding as positive responses about interest in robot-building activities | <ul style="list-style-type: none"> • "...because I enjoyed building it." • "I enjoyed getting to work on it" • "...because it was fun and interesting to make" • Keywords: making, programming, building, creating |
| | Interest in general tournament experiences | Coding as positive response about interest in experience in general: tournament, demonstrations | <ul style="list-style-type: none"> • "(I enjoyed) seeing its improvements" • "I really like playing with it" • "It's a very fun robot to bring to demonstrations and schools to teach kids about STEM." • "I get so hype[d] when I watch that robot climb!!" • Keywords used: seeing its improvement, watching it in matches, playing with it, get hype when watching that robot climb |
| | Interest in the subject | Coding as positive responses about interest in the subject | <ul style="list-style-type: none"> • "I really like robots and robotics" • "I am very fond of robotics" |
| | Lack of interest in activities | Coding as negative responses about activities | <ul style="list-style-type: none"> • "But the competition part of it gets boring because we have to wait for long period of times, before we see our robot compete again." |

Table 3 Continued

| Dimension | Category | Definition | Examples |
|----------------------|------------------------------------|--|--|
| Relatedness to robot | Positive connection with the robot | Coding as positive responses about the robot | <ul style="list-style-type: none"> • “he could be a pet.” • “I feel a personal connection to the robot” • “I feel pretty proud of the robot” • “...and the core of our team becomes very attached to each bot.” • “...because we made so many new memories and experiences with it.” • Keywords used: proud of the robot, pleased with, adorable, enjoy a close relationship with, love, bond, attach, personal connection, like, really like, like a lot, important, love how it turned out, baby/child, mechanical pet, so many new memories and experiences with it |
| | Lack of connection with the robot | Coding as neutral or negative responses about the robot | <ul style="list-style-type: none"> • “I've built enough robots that I am not very attached to newer ones that I've built.” • “I can live with out them” • “not like enough to think of it like a pet” |
| Autonomy | Self-involvement | Coding as statement of self-control and self-involvement in creating the robot | <ul style="list-style-type: none"> • “some elements that I agreed upon were considered” • “Because I helped build the robot” • “I had a big part in building the robot.” • Keywords used: I have built it, I drove it, I helped design, I helped control it, worked closely with the robot |
| | Lack of autonomy | Coding as stating not getting involved, no free choice | <ul style="list-style-type: none"> • “I had less input into the design of the robot than previous years” • “...but since I still had to work on it and drive it and still became familiar with it” |
| | Time and effort | Coding as putting in a lot of time/effort | <ul style="list-style-type: none"> • “I put so much work into my robot” • “I feel that because we put so much work towards the robot” • Keywords used: worked hard, a lot of work, worth our time |

Table 3 Continued

| Dimension | Category | Definition | Examples |
|-----------------------|---------------------------------|---|--|
| Competence | First time experience | Coding as the first robot ever built | <ul style="list-style-type: none"> • “It was a great robot for our first year” • “But it was the first robot I have made [and] our team has made.” |
| | Desire to do better | Coding as desire to do better and desire to win | <ul style="list-style-type: none"> • “We could've done a better job in the initial designing and execution.” • “...but could have included major improvements that would have won us the regional.” • Keywords used: could've, should've, would've, make it better, improve it |
| | Learning | Coding as explicitly stating learning | <ul style="list-style-type: none"> • “I got to learn how to work with a team” • “Because I have learned so much” |
| | Sense of confidence | Coding as the sense of confidence or accomplishment | <ul style="list-style-type: none"> • “Never in my life had I accomplished such a monumental feat with a team.” • “I'm proud to say I know every aspect of the drive train.” • Keywords used: feel proud, I was able to, accomplished my goal, a better problem solver, accomplish |
| | Lack of competence | Coding as lack of competence | <ul style="list-style-type: none"> • “...as a result I blame myself” • “Each time I work with this robot I am reminded of my shortcomings” |
| Relatedness to humans | Positive connection with humans | Positive responses to the human teams, team members, and mentors | <ul style="list-style-type: none"> • “I made it with friends” • “It was the first year my team learned to cooperate and created a product” • “When I joined the team I felt a strong bond with my team members and mentors, almost like a family.” • Keywords used: team united like a family, team members and mentors almost like a family, team cooperate to create a product |
| | Negative connection with humans | Negative responses about the humans (team, team members, mentors) | <ul style="list-style-type: none"> • “Due to unavoidable circumstances I was left to construct and deal with the majority of the robot on my own.” • “team couldn't decide what to focus on” • Keywords used: too much mentor intervention, left to work alone, not following the elements agreed upon, communication issue |

Table 3 Continued

| Dimension | Category | Definition | Examples |
|-----------|----------|---|--|
| Other | | Items that do not belong to any of the categories | <ul style="list-style-type: none"> • “I’m also very impatient.” |

Table 4 The Codebook of Reasons Students Liked the Robots More Because of Team Members

| Code | Definition | Examples |
|--|--|--|
| Enjoyment of teamwork and interactions | Coding as a general statement of enjoyment of working together and interacting with people | <ul style="list-style-type: none"> • “I liked it more because it’s fun to work with other people together when building the robot.” • “More. Its a group effort to bring it to life, and it makes it much more rewarding creating it as a team.” • “I enjoyed meeting other people and working with the team so it added to the positive experience.” |
| Social bond | Coding as a specific statement about human relationships | <ul style="list-style-type: none"> • “More, because it shows that our team is like a family and we all have the same common goal which is to promote our team in the community in terms of STEM and Business.” • “Other team members made me like the robot more because it gave us something to bond over and work on together.” • “More! My team allowed me to grow a bond with them and the robot.” • “I like it more because of them. Robotics has made us like a family in a way”. • Keywords used: a family, a close knit, with friends, a bond, comrade, a strong community, helping each other, great experience with peers |
| Team effort made robot possible | Coding as statement that team effort, ideas made the robot possible, better, best, unique | <ul style="list-style-type: none"> • “More, because if I did it all it would not work as well as it did. I do not know everything needed to make a robot. • “Yes because there were more inputs helping to make the robot the best that it could be.” • “More. Its a group effort to bring it to life, and it makes it much more rewarding creating it as a team.” |

Table 4 Continued

| Code | Definition | Examples |
|----------------------|---|---|
| Shared passion | Coding as shared passion, common goal, hard work, others passion enthusiasm | <ul style="list-style-type: none"> • “The overall enthusiasm of my team made my liking toward the robot grow.” • “Others were very passionate about the robot as well. This made me love it even more.” • “I think watching others work on the robot and how much effort they put forth almost made it seem like the robot had a personality. We affectionately called it the Peacemaker Mk. III.” |
| Learning and growing | Coding as personal growing and learning | <ul style="list-style-type: none"> • “More because they told me about how there robots were from the years before and how unique they were just like ours now.” • “I like the robot more knowing that it was a team effort, as a personal validation that I can work effectively in a team format and have enhanced by communicative and cooperative skills.” |

Table 5 The Codebook of Reasons Team Members Decreased Students’ Liking of Their Robots

| Code | Definition | Examples |
|------------------|--|--|
| Lack of Support | Coding as lack of support, help, and effort from their teams | <ul style="list-style-type: none"> • “I like the robot less because my team could not help me. I did not like building it alone. There was not enough multi-sided input and I wanted help.” |
| Lack of Autonomy | Coding as lack of autonomy support, denial of participation | <ul style="list-style-type: none"> • “My team members were great and I loved working with most of them. The reason for all the hate towards the team is the authoritarian mentors.” • “I was alienated from the designing process and competitions.” |
| Distractions | Coding as fights, arguments, and drama that slow things down | <ul style="list-style-type: none"> • “At the beginning there was a bit of in-fighting over robot design which made it hard to get excited about working on it.” • “There was too much drama on my old team.” |

CHAPTER 3

RESULTS

This chapter first presents the results of each variable, including involvement levels on a robotics team, perceived autonomy, perceived competence, perceived relatedness to humans, intrinsic motivation, self-regulated extrinsic motivation, effort and time input, and perceived relatedness to the robot. Then the chapter presents regressions using SDT as a framework to predict four dependent variables as depicted in research framework in Figure 3: intrinsic motivation, self-regulated extrinsic motivation, relatedness to the robot, and overall liking of the robot. The chapter also displays the differences in the dependent variables in the different levels of basic psychological needs, as well as correlations among these dependent variables.

Measures of Variables

Involvement levels with the robot. One possible way to divide the participants is by their involvement levels with the robot. The directly involved roles include the following kinds of tasks on a team: mechanical, electrical, programming, CAD, and driving the robot. The indirectly involved roles include the following types of tasks: mentoring, developing strategies and leadership, advocating on media, marketing, and cheerleading. Most participants had multiple tasks on a team (see Table 6). This study did not compare results based on the involvement levels because the majority ($N=116$; 95%) of the participants had directly involved tasks (see Table 7).

Table 6 The Roles and Responsibilities of Participants on a Robotics Team

| Types of Tasks | Explanation | N |
|--------------------------------|---|----|
| Mechanical | <ul style="list-style-type: none"> Conducting various tasks that are related to hardware of the robot, including making 3D printed parts | 88 |
| Electrical work | <ul style="list-style-type: none"> Designing, building, or troubleshooting the electrical components of the robot | 52 |
| Programming | <ul style="list-style-type: none"> Creating the software that runs the robot | 33 |
| CAD (Computer Aided Design) | <ul style="list-style-type: none"> Modeling and prototyping ideas and robot parts in Solidworks before, during, and after the build season | 29 |
| Driving | <ul style="list-style-type: none"> Controlling the robot on the competition field | 2 |
| Mentoring | <ul style="list-style-type: none"> Supervising students; providing feedback, ideas, or guidance when needed | 6 |
| Strategy and Leadership | <ul style="list-style-type: none"> Analyzing game rules and possible strategies, keeping up with the evolution of those strategies throughout the season, and tracking the performance of teams at the competitions that we attend. Meeting to ensure that tasks are being completed and that the team is running smoothly | 65 |
| Media | <ul style="list-style-type: none"> Promoting the team in news stories as well as on social media, including designing fliers, banners, and logos, etc. | 25 |
| Marketing | <ul style="list-style-type: none"> Writing grants, encouraging donations, developing relationships with existing and new sponsors, fundraising | 28 |
| Cheerleading | <ul style="list-style-type: none"> Cheerleading during the events | 47 |
| Other | <ul style="list-style-type: none"> Event planning, writing for chairman's award, safety captain/producing safety animation, scouting other teams, and editing the team engineering book | 14 |

Table 7 The Numbers of Valid Cases in Involvement Levels

| Involvement | Frequency | Percent |
|-------------|-----------|---------|
| Indirect | 6 | 4.9 |
| Direct | 116 | 95.1 |
| Total | 122 | 100.0 |

Perceived autonomy. Two items were used to measure the need for autonomy, one of which was reverse coded. Both “Wanting to participate” ($M = 8.27$, $SD = 2.54$) and “Having choices” ($M = 7.81$, $SD = 3.81$) had high average scores.

Perceived competence. The average score of this scale was 5.97 ($SD = 3.95$) on a -10 to 10 bar scale. Table 8 shows the descriptive statistics of the need for competence. The exploratory factor analysis resulted in one factor, which accounted for 58.83% of the variance of the perceived competence (see Table 9 for the factor loadings).

Table 8 Descriptive Statistics of Perceived Competence ($N = 101$)

| Variable | M | SD |
|---|------|------|
| The robot reflects my achievement. | 5.98 | 4.17 |
| The robot reflects my knowledge and skills in project management. | 5.61 | 3.98 |
| The robot reflects my knowledge and skills in robotics. | 5.84 | 4.25 |
| After working on robotics for a while, I felt pretty competent. | 6.54 | 3.50 |
| I am satisfied with my overall performance on the robot. | 5.90 | 3.86 |

Table 9 Factor Loadings for Exploratory Factor Analysis With Varimax Rotation of Competence Scale

| Items | Component |
|---|-----------|
| I am satisfied with my overall performance on the robot. | .70 |
| After working on robotics for a while, I felt pretty competent. | .77 |
| The robot reflects my achievement. | .74 |
| The robot reflects my knowledge and skills in robotics. | .85 |
| The robot reflects my knowledge and skills in project management. | .77 |

Note. Extraction Method: Principal Component Analysis. a. 1 component extracted.

Perceived relatedness to humans. The average score of the scale was 6.84 ($SD = 3.46$). Table 10 shows the summary of the intercorrelations, means, and standard deviations for the items. All three items in the scale were significantly correlated.

Effort and time input. The mean score of this item was 6.91 ($SD = 3.75$, $N = 75$, listwise deletion).

Table 10 Summary of Intercorrelations, Means, and Standard Deviations for Scores on the Items of the Need for Relatedness

| | 1 | 2 | 3 |
|---------------------|-------|------|------|
| 1. Promote outreach | – | | |
| 2. Talk to others | .51** | – | |
| 3. Teamwork | .30** | .18* | – |
| <i>M</i> | 6.16 | 7.41 | 6.96 |
| <i>SD</i> | 3.90 | 2.92 | 3.56 |

Note. * $p < .05$. ** $p < .01$ (2-tailed).

Intrinsic motivation. In the intrinsic motivation questionnaire, participants significantly liked building the robots ($M = 8.15$, $SD = 2.56$, $N = 110$) more than they liked playing with the robots ($M = 6.77$, $SD = 3.04$, $N = 110$, $t(109) = 4.45$, $p < .01$) (see Table 11).

Table 11 Summary of Intercorrelations, Means, and Standard Deviations for Scores on the Items of Intrinsic Motivation

| | 1 | 2 | 3 |
|--------------|-------|-------|------|
| 1. Building | – | | |
| 2. Playing | .33** | – | |
| 3. Rewarding | .62** | .30** | – |
| <i>M</i> | 8.08 | 6.77 | 6.91 |
| <i>SD</i> | 2.66 | 3.05 | 3.26 |

Note. * $p < .05$. ** $p < .01$ (2-tailed).

Self-regulated extrinsic motivation. Self-regulated extrinsic motivation included three items: the value of learning, the future self, and career goals (see Table 12 for a summary of the intercorrelations, means, and standard deviations for all items).

Overall liking of the robot. The overall liking of the robot ($M = 83.07$, $Min = 18$, $Max = 100$, $SD = 18.00$, $N = 78$; 22 people rated 100) is similar to previous study ($M = 82.61$, $SD = 21.03$) (Huang & Gillan, 2014).

Table 12 Summary of Intercorrelations, Means, and Standard Deviations for Scores on the Items of Self-Regulated Extrinsic Motivation

| | 1 | 2 | 3 |
|----------------|-------|-------|------|
| 1. Learning | – | | |
| 2. Future self | .63** | – | |
| 3. Career goal | .45** | .70** | – |
| <i>M</i> | 8.13 | 6.45 | 6.03 |
| <i>SD</i> | 2.80 | 4.21 | 4.29 |

Note. * $p < .05$. ** $p < .01$ (2-tailed).

Relatedness to the robot. Table 13 shows the descriptive statistics of the 13 items. Nine items had high ratings (over 5.00), including liking, feeling passionate, feeling praised, caring, having general feelings, feeling attached, feeling significant meaning, feeling sad about no function, and feeling close. Table 14 shows the mean score for the whole scale, the positive-response subscale, and the negative-response subscale.

Table 13 Descriptive Statistics of Relatedness to the Robot

| | M | SD | N |
|---------------------|------|------|-----|
| Liking | 8.31 | 1.80 | 78 |
| Feeling passionate | 7.69 | 2.78 | 80 |
| Feeling praised | 7.01 | 3.32 | 106 |
| Caring | 6.45 | 3.83 | 121 |
| Having feelings | 5.89 | 5.01 | 119 |
| Attachment | 5.65 | 4.23 | 119 |
| Significance | 5.48 | 3.87 | 108 |
| Sadness_no_function | 5.21 | 4.52 | 114 |
| Feeling close | 5.00 | 4.59 | 119 |
| Feeling good | 4.61 | 4.17 | 122 |
| Sadness_dismantle | 3.72 | 5.32 | 109 |
| Hurt_scratched | 2.89 | 4.88 | 107 |
| Feeling bad_no see | 2.38 | 5.24 | 106 |

Table 14 Descriptive Statistics of the Mean Scores of Relatedness to the Robot

| Relatedness to the Robot | M | SD | N |
|--------------------------|------|------|-----|
| Whole scale | 5.20 | 3.02 | 122 |
| Positive responses | 6.00 | 3.10 | 122 |
| Negative responses | 3.34 | 4.05 | 118 |

Confirmative factor analysis of the human–robot relatedness items resulted in two factors (see Table 15): positive responses toward interaction with and the present of the robot and negative responses when the robot is absent or damaged. These two factors accounted for 58.90% in the variance of the relatedness to the robot.

Table 15 Factor Loadings for Confirmative Factor Analysis With Rotated Component Matrix for Relatedness to the Robot

| | Component | |
|---|-----------|-----|
| | 1 | 2 |
| How much do you like the robot? | .52 | .18 |
| I am passionate about the robot. | .75 | .25 |
| I feel that I am attached to the robot. | .87 | .18 |
| I feel close to the robot. | .88 | .12 |
| I have no feelings for the robot. (R) | .72 | .10 |
| I care about the robot. | .76 | .31 |
| I feel good being with the robot. | .70 | .33 |
| The robot means a lot to me. | .65 | .38 |
| I would feel hurt if the robot got scratched or broken. | .23 | .73 |
| I would feel bad if I could no longer see the robot. | .54 | .59 |
| I would feel sad if the robot could no longer function. | .16 | .83 |
| If I had to dismantle the robot, I would feel sad. | .14 | .73 |

Note. Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.

Regression Models and Relationships Among Variables

The following section presents the regression models and the relationships among the independent variables and dependent variables.

Using the basic psychological needs to predict intrinsic motivation.

The three basic needs accounted for 57.5% of the variance in intrinsic motivation, $F = 48.16, p < .01$ (see Table 16). Perceived autonomy and competence were significant predictors for intrinsic motivation. Therefore, hypotheses 1a and 1b were supported, but 1c was not supported.

Table 16 Predictors of Intrinsic Motivation

| Variable | B |
|-----------------------|-------|
| (Constant) | 1.07 |
| Autonomy | .33** |
| Competence | .35** |
| Relatedness to humans | .08 |

Note. * $p < .05$. ** $p < .01$ (2-tailed).

Using the basic needs to predict self-regulated extrinsic motivation.

The three needs accounted for 58.4% of the variance in the self-regulated extrinsic motivation, $F = 50.16, p < .01$ (see Table 17). Perceived autonomy and competence were significant predictors of self-regulated extrinsic motivation, which was not the case for perceived relatedness to humans. Therefore, hypotheses 2a and 2b were supported, but hypothesis 2c was not supported.

Table 17 Predictors of Self-regulated Extrinsic Motivation

| Variable | B |
|-----------------------|-------|
| (Constant) | .96 |
| Autonomy | .21* |
| Competence | .71** |
| Relatedness to humans | -.01 |

Note. * $p < .05$. ** $p < .01$ (2-tailed).

Using the basic psychological needs to predict relatedness to the robot.

The descriptive statistics of the need for autonomy, the need for competence, the need for relatedness to humans, and human–robot relatedness are in Table 18. The three basic needs explained 36% of the variance of relatedness to the robot, $F = 20.03$, $p < .01$ (see Table 19). All three needs were significant predictors of relatedness to the robot. Hypotheses 4a, 4b, and 4c were supported.

Table 18 Descriptive Statistics of Autonomy, Competence, Relatedness to the Robot, and Relatedness to Humans

| Variable | M | SD | N |
|--------------------------|------|------|-----|
| Relatedness to the robot | 5.20 | 3.02 | 122 |
| Autonomy | 8.36 | 2.51 | 113 |
| Competence | 5.64 | 3.33 | 113 |
| Relatedness to humans | 6.88 | 2.58 | 111 |

Table 19 Predictors of Relatedness to the Robot

| Variable | B |
|-----------------------|-------|
| (Constant) | -.47 |
| Autonomy | .27** |
| Competence | .31** |
| Relatedness to humans | .24* |

Note. * $p < .05$. ** $p < .01$.

Testing intrinsic motivation as a mediator for relatedness to the robot.

The analysis added intrinsic motivation to the regression, then the regression model accounted for 36% of the variance of relatedness to the robot, with $F = 17.11$, $p < .01$ (see Table 20). Adding intrinsic motivation to the regression model made perceived autonomy

and competence non-significant, but intrinsic motivation was still a significant predictor.

These results suggested that intrinsic motivation mediated the relationships between the basic needs and relatedness to the robot. Perceived autonomy accounted for 12.25% of relatedness to the robot, competence 17.15%, relatedness to humans 21%, and intrinsic motivation 35% (see Figure 6).

Table 20 Predictors of Relatedness to the Robot, Including Intrinsic Motivation

| Variable | B |
|-----------------------|-------|
| (Constant) | -1.17 |
| Autonomy | .16 |
| Competence | .18 |
| Relatedness to humans | .21* |
| Intrinsic Motivation | .35* |

Note. * $p < .05$. ** $p < .01$.

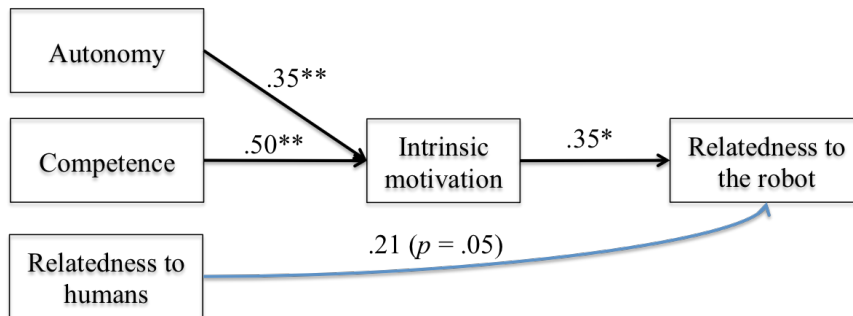


Figure 6. Model of intrinsic motivation as a mediator for relatedness to the robot.

Using the basic psychological needs to predict overall liking of the robot.

The three basic psychological needs accounted for 34.9% of the variance in liking of the robot, $F = 13.39$, $p < .01$ (see Table 21). Perceived autonomy and competence were significant predictors of liking, but relatedness to humans was not. Correlation analysis

showed that relatedness did not have a significant correlation with liking of the robot ($r = .05, p > .05$). Therefore, hypothesis 6a and hypothesis 6b were supported, whereas hypothesis 6c was not supported.

Testing intrinsic motivation as a mediator for liking of the robot.

The analysis added intrinsic motivation to the regression, and to see whether perceived autonomy, competence, and relatedness to humans significantly predicted liking of the robot. When intrinsic motivation was added, the three basic needs remained significant predictors, and the intrinsic motivation was not a significant predictor for liking of the robot. Therefore, intrinsic motivation was not a mediator for liking of the robot.

Table 21 Predictors of Overall Liking of the Robot

| Variable | B |
|-----------------------|--------|
| (Constant) | 42.93 |
| Autonomy | 3.84** |
| Competence | 3.12** |
| Relatedness to humans | -2.09* |

Note. $N = 79$, * $p < .05$. ** $p < .01$.

Relationships between effort and time input and the four outcomes.

The effort rating had positive correlations with intrinsic motivation, self-regulated extrinsic motivation, and relatedness to the robot. Therefore, hypotheses 3a, 3b, 3c were supported. But surprisingly, effort and time input did not have a significant correlation with the overall liking of the robot (see Table 22).

Table 22 Correlations Between Effort/time and Motivations and Relatedness to the Robot

| Measure | Extrinsic | Intrinsic | Relatedness to robot | Liking |
|-------------|-----------|-----------|----------------------|--------|
| Effort/time | .50** | .48** | .27* | .18 |

Note. * $p < .05$. ** $p < .01$ (2-tailed).

Relationships among intrinsic, extrinsic motivation, and relatedness to the robot.

Correlation between the intrinsic motivation and relatedness to the robot was significant ($r = .50, p < .01$) (see Table 23). Therefore, hypothesis 5a about the relationships between relatedness to the robot and intrinsic motivation toward the robotics activities was supported. Hypothesis 5b about the relationship between relatedness to the robot and self-regulated extrinsic motivation was also supported.

Table 23 Summary of Intercorrelations for Scores on Motivations, Liking, and Relatedness to Robot

| Measure | 1 | 2 | 3 | 4 |
|--|-------|-------|-------|---|
| 1. Intrinsic motivation | – | | | |
| 2. Self-regulated Extrinsic motivation | .68** | – | | |
| 3. Liking | .51** | .58** | – | |
| 4. Relatedness to the robot | .56** | .49** | .52** | – |

Note. * $p < .05$. ** $p < .01$.

Differences in intrinsic motivation among different levels of the basic needs.

We used tertile splits (Gelman & Park, 2012) to compare the difference in intrinsic motivation among low, medium, and high levels of perceived autonomy, competence, and relatedness to humans (see Table 24). In all three basic needs, intrinsic motivation had significant difference among the three levels. Post hoc comparisons using the Bonferroni test indicated that the mean score of intrinsic motivation for a high level of autonomy ($M = 8.54$,

$SD = 1.67$) was significantly stronger than a low level of autonomy ($M = 5.14$, $SD = 2.50$). The mean score of intrinsic motivation for a high level of competence ($M = 9.05$, $SD = 1.05$) was significantly stronger than for a low level of competence ($M = 5.07$, $SD = 2.55$). The mean score of intrinsic motivation for a high level of relatedness to humans ($M = 8.83$, $SD = 1.42$) was significantly stronger than for a low level of relatedness to humans ($M = 6.19$, $SD = 2.79$). Thus, hypotheses 1a, 1b, and 1c were again supported.

Table 24 Summary of Descriptive Statistics and Differences in Intrinsic Motivation Among Levels of the Basic Needs

| | Intrinsic motivation | | | | | |
|-----------------------|----------------------|------|------|------|-------|----|
| | Grp | N | M | SD | F | p |
| Autonomy | 1 | 33 | 5.14 | 2.50 | 31.43 | ** |
| | 2 | 22 | 6.85 | 1.78 | | |
| | 3 | 57 | 8.54 | 1.67 | | |
| | Total | 112 | 7.20 | 2.45 | | |
| Competence | Grp | N | M | SD | F | p |
| | 1 | 35 | 5.07 | 2.55 | 41.93 | ** |
| | 2 | 39 | 7.32 | 1.74 | | |
| | 3 | 38 | 9.05 | 1.05 | | |
| Total | 112 | 7.20 | 2.45 | | | |
| Relatedness to humans | Grp | N | M | SD | F | p |
| | 1 | 36 | 6.19 | 2.79 | 16.24 | ** |
| | 2 | 38 | 6.77 | 1.86 | | |
| | 3 | 37 | 8.83 | 1.42 | | |
| Total | 111 | 7.27 | 2.36 | | | |

Note. * $p < .05$. ** $p < .01$. Grp = Group

Differences in relatedness to the robot among different levels of the basic needs.

We also used tertile splits (Gelman & Park, 2012) to compare the difference in relatedness to the robot among low, medium, and high levels of perceived autonomy, competence, and relatedness to humans (see Table 25). For all three basic needs, relatedness to the robot had significant differences among the three levels. Post hoc comparisons using the Bonferroni test indicated that the mean score of relatedness to the robot for high level of autonomy ($M = 6.10$, $SD = 2.70$) was significantly stronger than the low level of autonomy ($M = 3.24$, $SD = 2.95$). The mean score of relatedness to the robot for high level of competence ($M = 6.99$, $SD = 2.33$) was significantly stronger than for a low level of competence ($M = 2.98$, $SD = 2.87$). The mean score of intrinsic motivation for a high level of relatedness to humans ($M = 6.48$, $SD = 2.84$) was significantly stronger than for a low level of relatedness to humans ($M = 3.60$, $SD = 2.80$). Therefore, results support hypotheses 4a, 4b, and 4c.

Reasons for Liking the Robot

Based on the codebook of reasons for liking the robot (see Table 3), the analysis of the essay responses to the question about the reasons for participants' levels of liking of the robot revealed the results in descending order (see Figure 7). The positive reasons included the robots' function and performance (robot feature), personal positive connection with the robot (relatedness to the robot), overall positive comments about the robot (robot feature), time and effort input, and self-involvement (autonomy), the robot form (robot feature), interest in building activities (intrinsic motivation), first robot ever built personally (competence), positive comments of the robot design (robot feature), interest in general

tournament experiences (intrinsic motivation), connection with other humans (relatedness to humans), sense of confidence (competence), and interest in robotics in general (intrinsic motivation). Then these reasons were grouped by dimensions, and the frequency of the dimensions was displayed (see Figure 8).

Table 25 Summary of Descriptive Statistics and Difference in Relatedness to the Robot Among Different Levels of the Basic Needs

| | Relatedness to the robot | | | | | |
|-----------------------|--------------------------|------|------|------|-------|----|
| | Grp | N | M | SD | F | p |
| Autonomy | 1 | 33 | 3.24 | 2.95 | 11.35 | ** |
| | 2 | 23 | 5.35 | 2.64 | | |
| | 3 | 57 | 6.10 | 2.70 | | |
| | Total | 113 | 5.12 | 3.01 | | |
| Competence | Grp | N | M | SD | F | p |
| | 1 | 36 | 2.98 | 2.87 | 23.03 | ** |
| | 2 | 39 | 5.26 | 2.42 | | |
| | 3 | 38 | 6.99 | 2.33 | | |
| Total | 113 | 5.12 | 3.01 | | | |
| Relatedness to humans | Grp | N | M | SD | F | p |
| | 1 | 36 | 3.60 | 2.80 | 9.77 | ** |
| | 2 | 38 | 5.36 | 2.75 | | |
| | 3 | 37 | 6.48 | 2.84 | | |
| Total | 111 | 5.16 | 3.01 | | | |

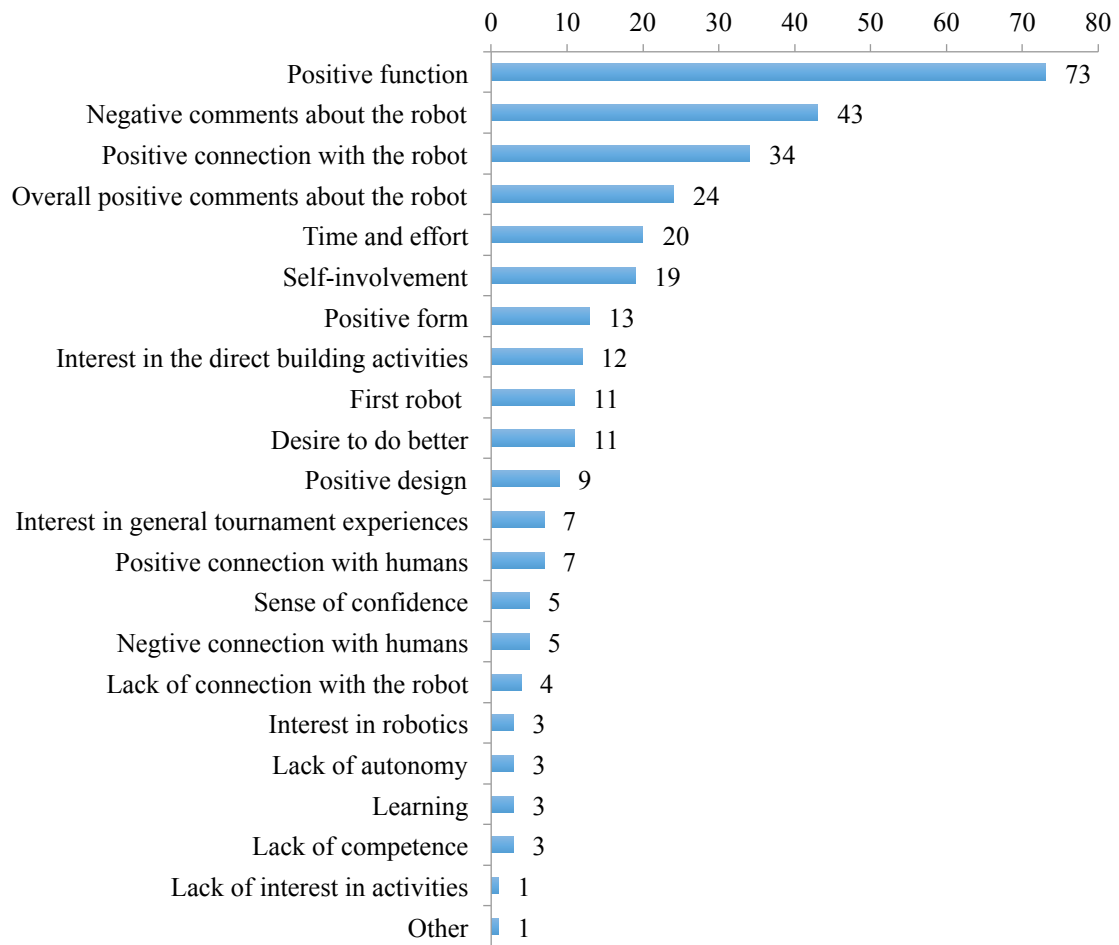


Figure 7. Frequency and types of reasons for liking the robot.

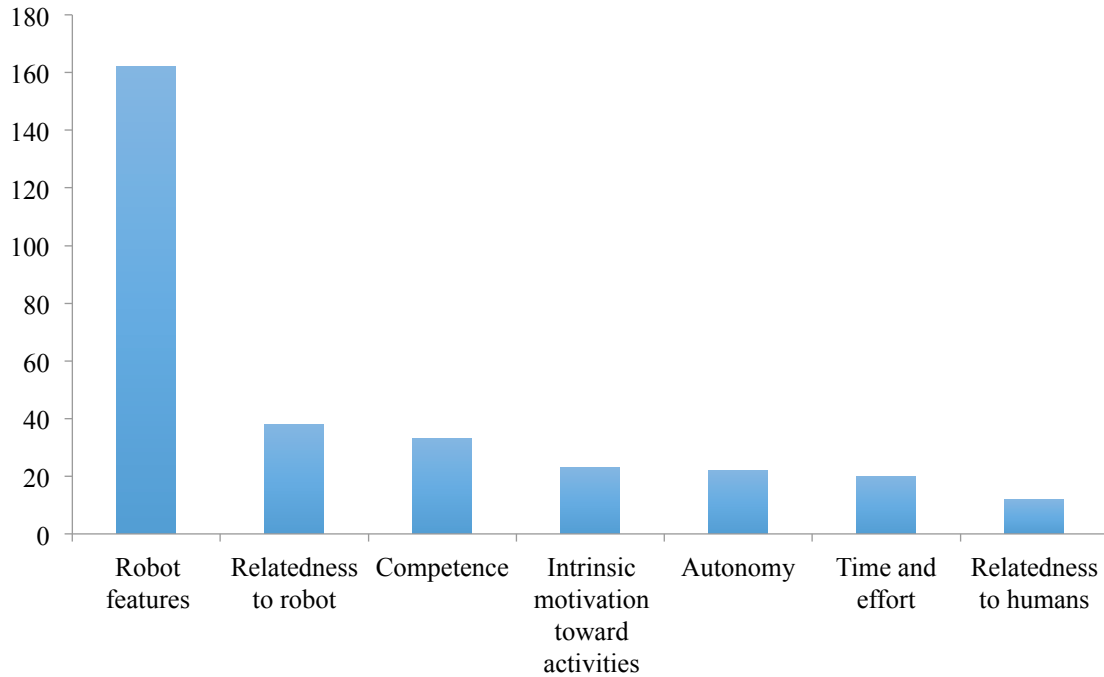


Figure 8. Frequency and types of reasons for liking the robot by dimensions.

Reasons for the Increase in Liking the Robot Because of Team Members

The second essay question (“Do you think the other team members working on the robot competition made you like the robot more or less? Please explain.”) explored the impact of team members on a person’s liking of the robot. The team members’ impact relates to the relatedness to humans. The frequencies of the impact—increasing, decreasing, or no change—were counted. The majority ($N = 76$; 62.3%) reported that their liking of the robot increased because of their team members. Based on the codebook in Table 4, the reasons fell under five main categories (see Figure 9 for an illustration).

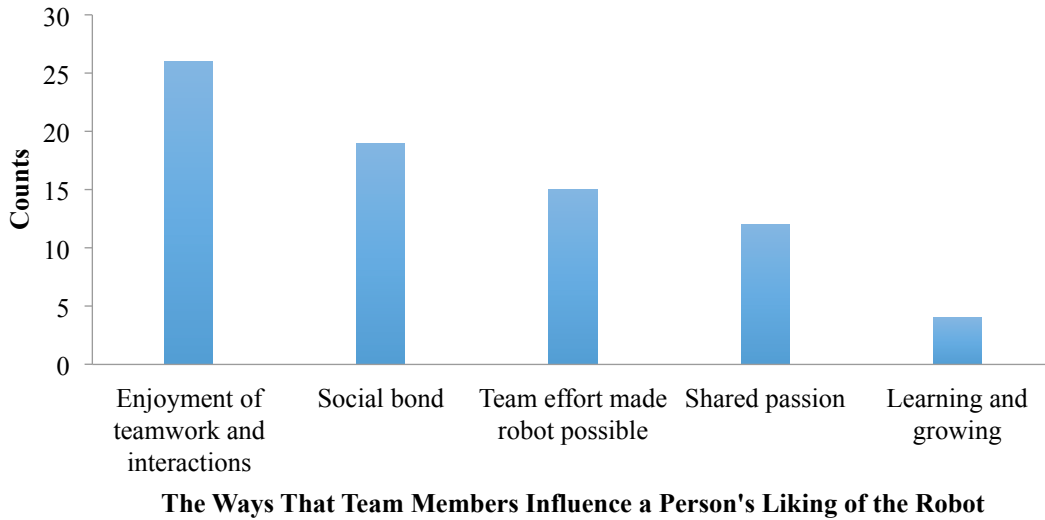


Figure 9. The reasons for liking the robot more because of team members.

Human–human relatedness and human–robot relatedness were different in rating scores, but they were correlated ($r = .27, p < .01$). The perceived relatedness to humans minimally predicted the relatedness to the robot ($R^2 = .07, F = 7.9, p < .01, N = 111$).

To further explore the relationship between relatedness to humans and relatedness to the robot using the essay question about team members and the scale question about the relatedness to the robots, the ratings on the scale question were coded at three levels:

- no relatedness—from -10 to 0
- low relatedness—from 0.01 to 4.99
- high relatedness—from 5 to 10

In the “no relatedness to the robot” group ($N = 6$), 16.7% of people stated that team members increased their liking of the robot. In the “low relatedness to the robot” group ($N =$

49), 61.2% of people stated that team members increased their liking of the robot. In the “high relatedness to the robot” group ($N = 67$), 67.2% of people stated that team members increased their liking of the robot. In other words, the higher the relatedness to the robot, the more likely people reported that they liked the robot more because of team members (see Table 26). Complementary to the survey, this result provided stronger evidence about the influence of human–human relationships on human–robot relationships.

Table 26 Influence of Team Members on Liking of the Robot

| Relatedness to robot | Humans’ influence on liking | Frequency | Percentage |
|----------------------|-----------------------------|-----------|------------|
| No | More | 1 | 16.7 |
| | Same | 3 | 50 |
| | Mixed Influence | 1 | 16.7 |
| | Missing | 1 | 16.7 |
| | Total | 6 | 100 |
| Medium | More | 30 | 61.2 |
| | Same | 7 | 14.3 |
| | Less | 5 | 10.2 |
| | Mixed Influence | 3 | 6.1 |
| | Missing | 4 | 8.2 |
| | Total | 49 | 100 |
| High | More | 45 | 67.2 |
| | Same | 11 | 16.4 |
| | Mixed influence | 1 | 1.5 |
| | Missing | 10 | 14.9 |
| | Total | 67 | 100 |

Note. More = liking of the robot increased because of team members; less = decreased; same = no change; mixed influence = increased in some situations, but decreased in others; missing = the answer did not indicate whether team members changed their liking of the robot or the box was blank.

CHAPTER 4

DISCUSSION

The goal of this dissertation was to explore (a) humans' motivation in interacting with robots and (b) humans' relationships with robots after long-term interactions. Thus far, very little work has been done on the application of Self-Determination Theory (SDT), a widely accepted theory about motivation in activities (Ryan & Deci, 2000b), to the study of human–robot interaction, particularly at robotics tournaments. SDT has been used to address humans' innate psychological needs and motivations toward activities, but it has not previously been applied to humans' relationships with the materialized creations of their activities. Therefore, this study examined human–robot relationships, investigating their relationships with the three basic needs and motivations in the SDT framework, using a new concept, human–robot relatedness.

This study employed a mix of quantitative and qualitative research methods, using an online survey to collect data from robotics tournament participants. Because application of SDT in robotics tournaments is still new in the HRI area, this exploratory study developed questions specifically for the research framework (see Figures 2 and 3) and the robotics tournament scenario. To test the validity of the number-based bar scale items, a few text-based essay questions were used to elicit more in-depth answers in case the scale questions neglected important aspects of people's motivation and relationship with robots, such as the reasons for liking the robot and the ways in which team members influenced each other's liking of the robot. The following section highlights the main findings of the study.

Perceived Autonomy

The results revealed that the participants in this study reported a high level of perceived autonomy: a majority of the students voluntarily chose to participate in the robotics tournaments. This result is favorable because youth's need for autonomy must be satisfied in order to support their cognitive and emotional development (Ryan & Deci, 2000a, 2000b). Maintaining and supporting students' autonomy is one of the key elements strengthening students' intrinsic motivation and positive emotions in their activities. The regression results supported the application of SDT to human-robot interaction by showing that perceived autonomy was a significant predictor for intrinsic motivation. In addition, perceived autonomy also predicted overall liking of and relatedness to the robot.

In practice, specific strategies for providing autonomy support may include allowing members to choose the tasks they would like to work on and encouraging students to freely express their preferences, ideas, creativity, and capabilities. The results of this study showed that the current practices of the FIRST robotics teams are fulfilling participants' basic need for autonomy, and therefore enhance their intrinsic motivation in the activities and their relatedness to the finished robots.

Perceived Competence

Perceived competence is a sense of perceived capability of doing tasks (Ryan & Deci, 2000b). This study showed that the 5-item scale had a high reliability, and the students had an average of 5.97 out of the 10-point scale competence subscale. In other words, the students felt satisfaction about their performance and competent about their abilities in general. They also felt that the robot reflected their knowledge and skills in robotics, as well

as management skills. However, their ratings were in the middle of the positive side of the competence scale, with room for an increase in competence. In the verbal data for the reasons for liking the robot (see Figure 7), 11 students (9%) reported that they wished they could have changed some aspects of the functions of the robot to make the robot perform better.

Like the regression analysis for perceived autonomy, the regression analysis for perceived competence also supported the use of Self-Determination Theory for HRI by showing that perceived competence was also a significant predictor for intrinsic motivation. In addition, perceived competence was also a significant predictor for liking of the robot and relatedness to the robot. A sense of accomplishment, good tournament results, and rewards are important for students to feel competent, but it is more important that the students perceived autonomy to do the tasks; specifically, that they had a sense of control with the amount of effort and time input, involvement in the development process, and agreement on the design. With the need for both autonomy and competence satisfied, the intrinsic motivation was enhanced, in alignment with the hypotheses from SDT.

Human–Human Relatedness and Human–Robot Relatedness

In robotics tournaments, students' relatedness to humans provides a vital role in the facilitation of intrinsic motivation, but the need for relatedness to humans seems to be secondary to the need for autonomy and competence. Caregivers normally provide autonomy support and help the care-receivers increase their competence (Ryan, Deci, & Grolnick, 1995).

In this research, perceived relatedness to humans did not predict intrinsic motivation in the regression analysis, a finding that contradicted the hypothesis about the positive

correlation between relatedness to humans and intrinsic motivation in SDT (Ryan & Deci, 2000b). Ryan and Deci (2000a) mentioned that individuals' inner resources may support their ongoing feelings of competence and autonomy; however, this may be only true for independent students who are persistent in pursuing the solutions, and not for students who get stuck in a problem and cannot go forward.

Another finding in this study was that perceived relatedness to other humans did not predict self-regulated extrinsic motivation about the value of learning, career goals, or the future self. One possible explanation might be that the measurement of relatedness to humans in this study only covered the liking of the teamwork, interaction with outreach audiences, and talking with friends about the robot; the study did not cover other aspects of relatedness, such as trust, feeling close, attachment, and reliance.

This work suggested using human–robot relatedness in contrast to human–human relatedness to describe the unique relationship between humans and robots. Previous research (e.g., Sung et al., 2008; Weiss et al., 2009) about humans' emotional attachment to robots is problematic because the definitions of attachment did not align with Bowlby's classic attachment theory (1982), which emphasized the safety regulation function of the attachment between caregivers and care-receivers. Human–robot relatedness is a more appropriate term for the close relationship between humans and robots because the human's relatedness to the robot contains the sense of self-extension and feeling of social bond and emotional tie, but it does not interfere with the strict boundary of Bowlby's concept of classic attachment (1982).

Human–human relatedness is different from human–robot relatedness in three ways: caregiving capabilities, communication, and emotion exchange. The first difference between

humans team members and robots is that human team members have the consciousness and potential to be sensitive to the human builders' needs and to be available to provide verbal and material resources to support the students in the building process. Human team members have the capability to be caregivers, whereas tournament robots, even finished ones, can only perform what the humans program them to do, and often do so inconsistently. Robots are the ones being created and taken care of, and thus are in the role of care-receivers. The second difference between human team members and robots is that human team members could use natural language and body gestures to communicate with the robot builders, but robots had limited sensors and responses for communication with humans. The third difference between human team members and robots is that whereas humans can recognize others humans' emotions and show emotions to other humans with natural language and body gestures, tournament robots have limited sensors and responses for emotion recognition or emotion expression. Thus, there was no emotion exchange between humans and robots.

One special characteristic about the tournament robots is that the robot builders implemented their thoughts on the robots through a long process of designing, building, and troubleshooting. The robot embodied the experiences. Furthermore, the tournament robots provided an opportunity for people with similar interests to work together as a team and to participate in outreach activities and competitions. Therefore, the finished robots may serve as visible reminders of the students' personally meaningful experiences and memories and thus is an embodiment of significant things related to the self, yet more than the self.

Human–human relatedness is a basic psychological need according to SDT, whereas human–robot relatedness is not a basic psychological need but a description of human–robot

relationship. Despite the current difference between human–human and human–robot relatedness, it is possible that they may be more similar in the future when technology advances to make robots that are indistinguishable from humans in the form and function. Even though the tournament robots lack the capabilities in emotions and caregiving capabilities, one participant reported that their team loved the robot as though it were their child. In addition, two participants reported the robot having anthropomorphized character and personality. Furthermore, one participant reported that the robot is an embodiment of the feeling of enjoying building and creating things and experiencing tournament. As said in the movie, *Eva* (2011), “It does not really matter whether robots feel or not, what really matters is what they make you feel.”

A surprising finding of the current study was that a person’s relatedness to humans negatively predicted his or her liking of the robot, even though liking of the robot was one aspect of relatedness to the robot. This finding indicates that relatedness to the robot is different from liking of the robot; the former includes more meanings, emotions, and attitudes than liking. When the participants responded to the essay question on whether and why team members influenced them to like the robot more or less, the majority of participants reported that team members caused them to increase their liking of the robot. Several reasons were cited: they enjoyed the teamwork, enjoyed the social bond, were encouraged by shared passion for robotics, valued working together to make the robot possible, and learned and grew because of the team. The group who had the highest rating of relatedness to the robot also reported the highest frequency of positive influence from other team members.

According to the analysis of participants' essay responses to the question "whether team members changed your liking of the robot to be more or less", participants acknowledged that team members increased a person's liking of the robot because team members working together made the robot possible for the tournament, and working as team could build a much better robots than any individual person possibly could with the given resources. Furthermore, other team members' hard work, shared passion in robotics, and enthusiasm increased a person's emotions toward the robot. When participants encountered difficulties in the building process, humans' support helped them overcome the obstacles. In a sense, people may have projected their connections with humans onto their relationship with the robots. The higher a person's relatedness was to the robot, the more likely that the person was to increase liking of the robot because of team members. A few people did report that other team members did not change their liking of the robot; they liked the robot simply because they wanted to build the robot, which might be one explanation for the fact that relatedness to humans negatively predicted the liking of the robot.

In the future, if the robots are able to satisfy one or more of humans' innate psychological needs, then human-robot relatedness may become close to human-human relatedness, or to loosely use Bowlby's term, emotional attachment. In the movie, *Big Hero 6* (2014), Hiro's brother Tadashi created the robot Baymax after numerous trials. Once Baymax was fully functional, he took care of Hiro's needs, helped Hiro to achieve his goals, and be a person Hiro socially connected with and trusted. This satisfied Hiro's needs for autonomy, competence, and relatedness. In this way, Baymax serves as a model for how a robot might come to stand in for a human caregiver.

Measurement of Human–Human Relatedness

The current study used three general questions to measure relatedness to team members, outreach audiences, and outside friends by asking how much they like their teamwork, or promotion activities, and talking to others about their robot. Team members, outreach audiences, and friends are three big groups of people and each group has subgroups of roles, such as mentors, parents, and peers. In addition to asking about a person’s feeling about the team members in a general question, it might be helpful to break it down into different subgroups based on roles. Wellborn and Connell (1987) showed how to break down the groups using the following statement: “When I am with __ (e.g., mentor, members, coach), I feel __ (e.g., relaxed, ignored, happy)... ” They also asked participants to rate the question on a 4-point scale (from almost always to almost never). Future research could tailor the questions to measure relatedness to teammates, parents, mentors, and coaches, and the level of the feelings (Ryan & Connell, 1989).

Measurement of Motivation Toward Specific Tasks in HRI

Ryan and Connell (1989) examined elementary students’ motivation on four categories of tasks: doing homework, working on classwork, trying to answer questions in class, and a global issue of trying to do well in school. Their method indicated that different tasks may be supported by different motivations—intrinsic or extrinsic or a mixture of the two. The current research asked people’s reasons for liking the robot, without breaking down the robotics tournament activities into specific aspects, such as building, programming, or marketing. General questions tend to result in general answers, so it might be vague for people to answer what aspects of the robotics tournament that they like or dislike and for

what reasons. Future research could ask questions regarding participants' reasons for their interest in a few major tasks on a robotics team.

Reasons for Liking the Robot

The essay responses to the question about the reasons for a person's chosen level of liking the robot not only covered the variables (the basic psychological needs, intrinsic motivation, and human-robot relatedness) measured in the quantitative method, but also provided rich examples of each variable. The types of reasons included the following: robot features (positive comments about robot design, positive comments about robot form and appearance, positive comments about robot function, overall positive comments of the robot, negative comments about robots' design, form, function, and overall impression); intrinsic motivation (interest in the robot-building activity, interest in the tournament experiences in general, interest in the subject of robot/robotics, and lack of interest in robotics activities); autonomy (self-involvement and lack of self-involvement); competence (first-time accomplishment, desire to do better, learning, sense of competence, and lack of sense of competence); relatedness to humans (positive connections with humans and negative connections with humans); relatedness to the robot (positive connections with the robot and lack of connections with the robot), and effort/time input (emphasis on the great effort and time input) (see Table 3 for definitions and examples and see Figure 7 for counts of each type of content). The statements enriched the dimensions and word choices of the variables investigated in the quantitative portion of the study and provided more hypotheses to be tested in future research. For example, the more autonomous the reason for liking the robot, the more likely it was to be associated with self-related enjoyment (Ryan & Connell, 1989).

Intrinsic Motivation as a Mediator for Human–Robot Relatedness

The mediator analysis results showed that intrinsic motivation mediated the effect of perceived autonomy and perceived competence on relatedness to the robot. Perceived relatedness to humans contributed to the relatedness to the robot more than perceived autonomy and competence. In this study, the rewards and competition did not seem to undermine students' intrinsic motivation in robotics activities. Students may have used coping strategies that helped prevent the tangible rewards and pressure of competitions from undermining their intrinsic motivation. Future research could explore what coping strategies worked in these settings and whether the satisfaction of one's innate psychological needs offsets the negative influence from the extrinsic rewards.

Coexistence of Intrinsic Motivation and Extrinsic Motivation

The results showed that the students' intrinsic motivation in the robotics activities positively correlated with self-regulated extrinsic motivation about growing and goals. This result means that both intrinsic motivation and self-regulated extrinsic motivation existed among the participants. Not all elements of robotics tournaments were inherently interesting all the time, so participants might have drawn on extrinsic motivation to pull through difficult times. However, it is clear that participants' intrinsic motivation has more benefits than their extrinsic motivation, such as deeper conceptual learning and healthier personal and emotional development (Ryan & Deci, 2000b). Research has shown that it is possible to facilitate the internalization of extrinsic motivation so that it becomes intrinsic motivation and eventually supports well-being (Ryan & Deci, 2000b). In this study, the measurement items in the self-regulated extrinsic motivation scale were self-regulated because they were self-initiated

goals, but they were extrinsic because the goals were beyond the activities, rather than the enjoyment of the activities per se (Vansteenkiste et al., 2006). The internalization process may be facilitated by providing meaningful rationales, recognizing the person's perspectives, and conveying choices rather than controls (Deci, Eghrari, Patrick, & Leone, 1994).

Implications of this Study

Using SDT, this work contributes to the research on Human–Robot Interaction by exploring robot builders' intrinsic motivation in robotics tournaments and their relatedness to their robots, as well as the influence of the satisfaction of the three basic psychological needs on the intrinsic motivation and human–robot relatedness. This research was conducted in the robotics tournament scenario, but the principle of the basic psychological needs applies to different tasks with different types of robots. The form may differ depending on the situations. In other words, to motivate people to interact with robots or to increase their positive relationships with the robot, the design of the robot or implementation of the robot in humans' life should take users' needs for autonomy, competence, and relatedness to other humans into consideration.

For educators in robotics tournaments, fulfilling students' three basic psychological needs would enhance students' intrinsic motivation, high-level learning, and positive emotions toward the robots. Mentors and parents' getting involved in students' robotics activities, offering them free choices, operating minimal controls, providing optimal challenges, and acknowledging students' perspectives are likely to help satisfying their innate psychological needs (Ryan & Deci, 2000b).

HRI researchers may apply the SDT framework to explore the specific applications of the basic psychological needs and typical motivations of the potential users of a particular robot. Similarly, HRI designers may design robot interfaces or functions that provide choices, positive feedback, and connection with supportive others to satisfy users' needs for autonomy, competence, and relatedness to other humans. Robots should not be designed to replace humans but rather to assist human caregivers or instructors.

Practitioners, such as nursing home workers and employees of education centers where assistive robots are used in classrooms, may also find this work interesting. The findings may help them to engage their patients or students in activities with robots. Understanding the students' specific needs for autonomy, competence, and relatedness to humans can increase users' interest and interactions with particular robots to fulfill health or educational purposes. When handling uninteresting tasks, providing rationales for doing the tasks, offering free choices, acknowledging their negative feelings about things may help patients and students internalize their motivation in interactions with robots to have a better mental health condition and learning (Deci, Eghrari, Patrick, & Leone, 1994).

Limitations of the Research

This dissertation used largely middle class white sample in the US. The questionnaires used some items that were developed for humans' interactions with tournament robots. The reliability of two of customized scales was relatively low in the present study due to the small number of scale items. These factors need to be considered when generalizing the results to other populations.

Future Directions

This study used questionnaires that were developed for the application of SDT in robotics tournaments. Future research is needed to validate the questionnaires so that they can be generalized to scenarios other than robotics tournaments. In addition, fully analyzing students' essay responses to questions about their reasons for liking their robots, and about how the team members influenced their relatedness to the robots, will complement the quantitative data in this study. The content validity of future research questionnaires will be improved by incorporating the reasons for participants' liking of their robot and for their relationships with other team members. Furthermore, investigation of strategies that increase students' perceived autonomy and perceived competence may help robotics tournament organizers and developers build on the current effective strategies and further facilitate students' intrinsic motivation and personal development. Finally, future research is needed to investigate extrinsic motivations in robotics activities that are not intrinsically motivating.

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