Team Learning Behaviors: Supporting Team-Based Learning in a First-Year Design and Communications Course

Ms. Nicole Lynn Larson, University of Calgary

Nicole is completing her PhD in Industrial Organizational Psychology at the University of Calgary under the supervision of Dr. Thomas O’Neill. She has been working with the Schulich School of Engineering for the past three years. During this period she has been involved in several initiatives, such as assessing student learning and engagement, implementing systems for peer evaluations, and leading teamwork training sessions. Nicole is currently conducting research on team learning processes in engineering student project teams. Additionally, she has co-developed a framework for measuring and interpreting an array of team dynamics. An online assessment tool has been created based on this framework which allows teams to diagnose and improve the “health” of their team. She is passionate about her area of research and plans to continue conducting research on factors that contribute to effective teamwork.

Ms. Genevieve Hoffart, University of Calgary

Genevieve is a first year M.Sc. student under the supervision of Dr. Thomas O’Neill at the University of Calgary focusing on at team dynamics, training, and communication. She has been working with the Schulich School of Engineering for the past four years during which time her focus has been on improving team dynamics and maximizing the student experience. In addition co-developing a communication training framework that has now been applied to over 3500 students campus wide, Genevieve has personally facilitated many of the training sessions. Her goal is to continue working on developing applicable and universal tools to improve the experience and functioning of student teams in institutions across North America.

Dr. Tom O’Neill, University of Calgary

O’Neill is a Professor of Industrial/Organizational Psychology and a leading expert in the areas of team dynamics, virtual teams, conflict management, personality, and assessment. He is director of the Individual and Team Performance Lab and the Virtual Team Performance, Innovation, and Collaboration Lab at the University of Calgary, which was built through a $500K Canada Foundation for Innovation Infrastructure Grant. He also holds operating grants of over $300K to conduct leading-edge research on virtual team effectiveness. Over the past 10 years, Tom has worked with organizations in numerous industries, including oil and gas, healthcare, technology, and venture capitals. He is currently engaged with the Schulich School of Engineering at the University of Calgary to train, develop, and cultivate soft-skill teamwork competencies in order to equip graduates with strong interpersonal and communication capabilities.

Prof. Marjan Eggermont, University of Calgary

Marjan Eggermont is the current Associate Dean (Student Affairs) and a Senior Instructor and faculty member at the University of Calgary in the Mechanical and Manufacturing department of the Schulich School of Engineering, University of Calgary. She teaches graphical, written and oral communication in their first Engineering Design and Communication course taught to all incoming engineering students. She co-founded and designs ZQ, an online journal to provide a platform to showcase the nexus of science and design using case studies, news, and articles. As an instructor, she was one of the recipients of The Allan Blizzard Award, a Canadian national teaching award for collaborative projects that improve student learning in 2004. In 2005, she was one of the recipients of the American Society of Mechanical Engineers Curriculum Innovation Award. She is - as PIC II chair - currently a board member of ASEE.

Dr. William Daniel Rosehart P.Eng., University of Calgary

Bill Rosehart, Professor in Electrical and Computer Engineering, has been in the University of Calgary’s Schulich School of Engineering since 2001. He has served in various administrative roles including Dean, Department Head, Associate Head (Undergraduate Studies), Director of the Electrical Engineering
Program, and Associate Director of the Energy and Environment specialization within the Schulich School of Engineering.

He was a founding member of Canadian Engineering Education Association (CEEA), and was a member of the CEEA's Governing Board as the Western Canada Regional Director from 2011 through 2013.

He is registered as a Professional Engineer in Alberta through the Association of Professional Engineers and Geoscientists of Alberta (APEGA).
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Abstract

Background: This research paper describes a study that investigated two types of team learning behaviors – exploring and exploiting – in the context of first-year engineering student teams. Exploration and exploitation are classified as two distinct learning activities. Exploratory learning (the pursuit of new knowledge) involves flexibility, variation, and experimentation. Exploitative learning (use of existing knowledge) involves refinement, efficiency, and execution of work. Thus, exploratory learning involves acquiring new capabilities, whereas exploitative learning involves refining existing knowledge and abilities.

We hypothesized that, at early stages of a teams’ project work, exploratory behaviors are helpful while exploitative ones are harmful. Importantly, at later stages this relationship reverses. At some point teams need to transition from acquiring knowledge to refining and executing based on that knowledge. Accordingly, at later stages, exploitative behaviors may be helpful whereas continued exploratory behaviors may distract from successful execution of the work.

Goal orientation (GO) is a dispositional, motivational orientation that directs an individual’s approach to achievement situations. There are two primary types of GOs: learning goal orientation (LGO) and performance goal orientation (PGO). Team members’ traits can be averaged to represent the team’s aggregate trait level, which can be predictive of team processes and performance. Thus, we consider dispositional GO at the team-level as an antecedent of team-level learning behavior.

LGO is characterized by a drive to explore new topics or techniques with an emphasis on gaining new skills and expertise. In contrast, PGO is described as a concern for executing and accomplishing work in order to receive external rewards and demonstrate ability. Thus, PGO individuals seek to demonstrate competence, whereas LGO individuals seek to build competence. We hypothesized that teams high on LGO will spend more time engaged in exploratory learning because it offers a chance to gain new knowledge. On the other hand, we predicted that high PGO teams will engage in learning behaviors that have a stronger connection to task completion. Given the uncertain nature of exploring, PGO teams may be more likely to focus on exploitative learning activities in order to build on existing certainties.

Method: The sample consists of 540 students (29% female) enrolled in an engineering design and communication course in a large North American university. Students were arranged into 4-person teams and were required to build a functioning prototype of a rover capable of picking up and displacing a rock. Learning measures were collected during lab each week over the course of the project. Additionally, we collected trait information (i.e., Goal Orientations) from all students at the beginning of the study. After teams presented their prototype, teaching assistants completed innovation ratings for the teams in their lab section. Random coefficient modeling, a multi-level procedure that handles non-independence of observations, was used to test the study hypotheses.
Results: Results indicated that teams tend to pursue both learning actions simultaneously and increase these behaviors over time, however these learning behaviors were not related to subsequent innovation performance. Additionally, we found that the composition of team members’ personality traits predicted the type of learning behaviors that teams engaged in. Specifically, teams consisting of members with high LGOs engaged in significantly more exploratory learning exploratory than teams lower on this trait. Interestingly, teams with a high PGOs engaged in greater levels of exploitative learning behaviors.

Implications: The implications of the study findings are three-fold. First, our research highlights the importance of considering team composition variables when grouping students into project teams. Second, it calls attention to the temporal nature of exploratory and exploitative learning activities. Third, it suggests future research is needed to examine the implication of these learning activities on outcomes other than innovation (e.g., individual learning, project grades, team potency).

Introduction
Engineering educators implement team-based project work expecting it will lead to interpersonal skill development, knowledge sharing, information dissemination, and individual and team learning. Unfortunately, practice has outpaced research, reflected in a lack of studies on team learning processes1, and a call for more research on team-level learning behaviors2,3. Although many instructors place a high value on collaborative team-based learning, the challenge resides in understanding and supporting team-level learning behavior.

Two key types of learning behaviors are particularly relevant in the context of teams: exploratory and exploitative learning. Despite origins in the macro organizational learning literature4, the exploration-exploitation paradigm is particularly relevant to the study of team learning. Exploratory learning involves acquiring new capabilities, whereas exploitative learning involves refining existing ones4. Understanding the role of team-level exploratory and exploitative learning is important because it can offer new insights into how student project teams learn collaboratively and, in turn, perform.

Exploratory and Exploitative Learning
March’s (1991) seminal article classifies exploration and exploitation as two distinct learning activities4. Exploratory learning (the pursuit of new knowledge) involves flexibility, variation, and experimentation. By contrast, exploitative learning (use of existing knowledge) involves refinement, efficiency, and execution of work5. Kostopoulos and Bozionelos (2011) suggested teams should pursue both exploration and exploitation in order to maximize performance3. That research, however, was not longitudinal. Importantly, whether exploratory and exploitative activities help or harm the team may depend on when they occur.

One noteworthy model considering the role of time in teams is Gersick’s (1988) punctuated equilibrium model6 (Figure 1). Gersick’s model predicts that teams show little observable progress at first, but experience a crucial transition point around the project midpoint6. Combining Gersick’s and March’s (1991) models, a logical transition would be from exploratory learning behaviors at first to exploitative behaviors past the midpoint. The rationale is that exploratory behaviors are often necessary and helpful when beginning a new unfamiliar project.
At those early stages, using existing knowledge may be insufficient. Thus, at early stages, exploratory behaviors are helpful while exploitative ones are harmful. Importantly, at later stages, this relationship reverses. At some point the team needs to transition from acquiring knowledge to refining and executing based on that knowledge. At those later stages, exploitative learning behaviors would be helpful whereas continued exploratory behaviors may distract from execution and delivery.

Figure 1
Gersick’s Punctuated Equilibrium Model

**Team Learning and Innovation**

Learning plays a central role in innovation. Previous research has found that team learning results in an ability to identify and generate novel solutions. West (1990) identified four events involved in innovation: recognizing opportunity, initiating a process, implementation, and stabilizing. Such phases of innovation map on to the learning constructs examined in the current study. In other words, exploration may lead to the recognition of previously unforeseen opportunity and result in the initiation of a process to capitalize on the discovery. Whereas, exploitation entails refining ideas and implementing them in an effective manner that stabilizes the innovation as a viable solution. Thus, innovation contains two stages: idea generation and implementation. Accordingly, innovation is considered an appropriate team outcome variable in the context of the current study. Taken together, increasing the effectiveness of learning processes could offer an innovative advantage to teams, through flexibility and implementation.

Marks and colleagues (2001) posit that team outcomes, including innovation, are enabled through the sequencing and timing of member actions. Indeed, high performing teams explore multiple ideas; however, increased variation is an inherent risk associated with exploratory behavior. In project teams, exploratory behavior is likely necessary for innovation during the
initial idea generation phase, whereas an overemphasis on exploitative learning may result in insufficient experimentation, resulting in suboptimal solutions. As such, high degrees of exploration past the project midpoint may be harmful to overall team performance through the creation of uncertainty and excessive variation. However, as teams move past the midpoint, behaviors that exploit the team’s knowledge base would become increasingly important for performance by assuring the implementation of an innovative idea\textsuperscript{15}. In other words, exploitative learning likely becomes more important during later phases of a team’s work, whereas exploratory learning is more important during earlier phases of a team’s work.

Goal Orientation and Team Learning
Goal orientation (GO) can be described as a dispositional, motivational orientation that directs an individual’s approach to achievement situations\textsuperscript{16}. Button, Mathieu, and Zajac identified two primary GOs: learning goal orientation (LGO) and performance goal orientation (PGO)\textsuperscript{17}. LGO is characterized by a drive to explore new topics or techniques with an emphasis on gaining new skills and expertise. In contrast, PGO is described as a concern for executing and accomplishing work in order to receive external rewards and demonstrate ability. Thus, PGO individuals seek to demonstrate competence, whereas LGO individuals seek to build competence. Barrick and colleagues suggested team members’ traits can be averaged to represent the team’s aggregate trait level\textsuperscript{18}, which can predict team processes and performance\textsuperscript{19,20,21}. Thus, we consider dispositional GO at the team-level as an antecedent of team-level learning behavior.

LGO fosters an interest in skill and knowledge acquisition; therefore, teams composed of members who are high on LGO are likely to value exploratory behaviors that may lead to new knowledge development. Additionally, previous research has found a positive relation between LGO and innovative behaviors such as idea generation, investigation, and skill acquisition\textsuperscript{22,23}. Thus, we expect that teams high on LGO will spend more time engaged in exploratory learning behaviors. Although high LGO is likely beneficial during early project stages, it may be detrimental if teams continue to explore beyond a certain point. Exploration late in the project may reduce team members’ confidence in the existing course of action. While, it is difficult to determine the optimum level of learning-related behavior for a given situation\textsuperscript{5}, we predict that teams with high LGO are predisposed to prefer exploration and are likely to engage in more exploratory behavior throughout all stages of work. However, teams with a weak LGO will engage in less exploratory behavior, and for these teams, exploratory behaviors may taper off after the project midpoint.

High PGO individuals strive to demonstrate competence and focus on task performance by practicing and mastering familiar task components and strategies\textsuperscript{24}. Thus, teams composed of high PGO individuals may engage in learning behaviors that appear to have a stronger connection to task completion. Given the uncertain nature of exploring, PGO teams may be more likely to focus on exploitative learning to refine and build on existing certainties. This proposition also aligns with previous research that PGO individuals prefer less ambiguous task work\textsuperscript{24}. Following the above, high PGO teams are likely to engage in more exploitative learning throughout the entire project, and thus will start higher on exploitative learning. Furthermore, in line with the punctuated equilibrium model, teams with weak PGO may be driven primarily by project deadlines, and thus will start low on exploitative learning and increase the frequency of these behaviors as the deadline approaches.
Methods and Procedure
The sample consisted of 540 students (29% female) enrolled in an engineering design course at a large North American University. Students formed 4-person teams at the beginning of the semester and completed four team-based projects from September to December. Data was collected during the fourth and final team project worth 25% of the students' overall grade, which required teams to build a functioning prototype of a rover capable of picking up and displacing a rock.

Prior to beginning Project 4, students completed the GO scale. Team learning behavior was measured at three time points over five weeks. There were 23 lab sections, each with approximately six teams that were supervised by a teaching assistant (TA). After teams presented their functioning prototype on the last day of class, each TA completed innovation ratings for teams in their individual section. A training session was provided to show TAs how to use the rating scale.

Learning behaviors were measured using definitions adapted from Kostopoulos and colleagues. The Relative Percentile Method (RPM) formed the basis for the rating scale used to assess team learning, which provided a meaningful comparison point for behaviors occurring in previous weeks. More specifically, teams responded collectively to two RPM items measuring: (1) exploratory and (2) exploitative learning activities. Each item provided a detailed description of the learning behavior, and teams indicated the degree to which they engaged in the behavior over the past week. On a percentile continuum, teams marked the point that best represented their weekly behavior for each dimension (see appendix A). In following weeks, teams were given the form containing their previous responses and again marked the position best corresponding to their weekly learning behavior. Previous research has supported the accuracy of the consensus approach, and in order to avoid survey fatigue this method of data collection was most suitable.

GO was measured using a 16-item scale developed by Button and colleagues. This included 8-items measuring LGO ($\alpha = .85$) and 8-items measuring PGO ($\alpha = .84$). Responses were based on a five-point Likert scale (strongly disagree to strongly agree) and were operationalized at the team-level by computing the mean from individual member’s responses. Per Barrick’s suggestions, within-team agreement was not necessary for aggregation of traits.

Innovation ratings were collected from domain-relevant experts who were all graduate-level TAs familiar with the course. Each TA rated only the teams in their individual lab section. In the aforementioned TA training, we included coaching to calibrate TAs perceptions of what constitutes innovation before they completed their ratings (see appendix B). The RPM formed the basis for the rating scale used to measure innovation. Team innovation was defined as the extent to which the team’s prototype embodied both a) the existence of a novel, unique, and original idea, and b) the effective implementation of the idea and functionality of the prototype. Ratings of innovation were z-scored to standardize within rater.

Results
We applied random coefficient models (RCM) to examine study hypotheses using Bliese and Ployhart’s model estimation procedures, the statistical program R, and the Nonlinear and
Linear Mixed Effects package (i.e., nlme). Following Bliese and Ployhart, we first tested an intercept-only model to assess the amount of variance in learning residing between and within teams. Intraclass correlations (ICC) indicated a nontrivial degree of non-interdependence for exploratory and exploitative learning. Specifically, 46.7% and 41.4% of the total variance in exploratory and exploitative learning, respectively, resided between teams. See Table 1 for correlations among study variables.

Table 1
Means, Standard Deviations, Correlations, and Reliabilities for Study Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>SD</th>
<th>n</th>
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<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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</tr>
<tr>
<td>1. Exploratory Learning</td>
<td>67.02</td>
<td>18.11</td>
<td>134</td>
<td>-</td>
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<td></td>
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<tr>
<td>2. Exploitative Learning</td>
<td>66.13</td>
<td>17.40</td>
<td>134</td>
<td>.44*</td>
<td>-</td>
<td></td>
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<tr>
<td>3. Exploratory Learning</td>
<td>73.02</td>
<td>16.91</td>
<td>133</td>
<td>.64*</td>
<td>.25*</td>
<td>-</td>
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<td></td>
<td></td>
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<tr>
<td>4. Exploitative Learning</td>
<td>72.99</td>
<td>15.72</td>
<td>133</td>
<td>.31*</td>
<td>.55*</td>
<td>.63*</td>
<td>-</td>
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<td><strong>Time 3</strong></td>
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<tr>
<td>5. Exploratory Learning</td>
<td>79.48</td>
<td>19.39</td>
<td>132</td>
<td>.46*</td>
<td>.33*</td>
<td>.55*</td>
<td>.36*</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Exploitative Learning</td>
<td>79.25</td>
<td>17.18</td>
<td>133</td>
<td>.18*</td>
<td>.36*</td>
<td>.44*</td>
<td>.63*</td>
<td>.60*</td>
<td>-</td>
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<tr>
<td><strong>Covariates</strong></td>
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</tr>
<tr>
<td>7. Innovation Rating</td>
<td>61.55</td>
<td>22.33</td>
<td>133</td>
<td>.11</td>
<td>.16</td>
<td>.05</td>
<td>.07</td>
<td>.08</td>
<td>.06</td>
<td>-</td>
<td></td>
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<tr>
<td>8. Learning GO</td>
<td>4.15</td>
<td>0.29</td>
<td>135</td>
<td>.34*</td>
<td>.21*</td>
<td>.27*</td>
<td>.18*</td>
<td>.18*</td>
<td>.10</td>
<td>.13</td>
<td>(.85)</td>
<td></td>
</tr>
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<td>9. Performance GO</td>
<td>3.90</td>
<td>0.35</td>
<td>135</td>
<td>.14</td>
<td>.22*</td>
<td>.06</td>
<td>.09</td>
<td>.12</td>
<td>.23*</td>
<td>.11</td>
<td>.03</td>
<td>(.84)</td>
</tr>
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</table>

* p < .05., and +p = .05

A time factor was set to predict learning scores at each time point (Table 2). Conceptually, this involved regressing learning measures onto time, and thus the intercept indicates initial levels of learning (i.e., time 1), and the time factor reflects the extent to which, on average, learning behaviors change over time. Interestingly, the rate of exploratory learning was positive and significant rather than negative, suggesting that exploratory learning increased by 6.24 at each consecutive time point. We predicted that exploitative behavior would have a positive slope over time, which was supported as results reveal a positive linear trend with an average increase of 6.56 points at each time point.

Table 2
Growth Model Parameter Estimates of Predictors of Exploratory and Exploitative Learning

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>SE</th>
<th>df</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
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<td>Final Level 1 model - Explore</td>
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<td></td>
<td></td>
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<tr>
<td>Intercept</td>
<td>66.92</td>
<td>1.53</td>
<td>264</td>
<td>43.74</td>
<td>&lt; .001</td>
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<tr>
<td>Time</td>
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<td>0.85</td>
<td>264</td>
<td>7.34</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Final Level 1 model - Exploit</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>66.22</td>
<td>1.45</td>
<td>265</td>
<td>45.69</td>
<td>&lt; .001</td>
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<tr>
<td>Time</td>
<td>6.55</td>
<td>0.85</td>
<td>265</td>
<td>7.73</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

Note: n = 405 observations nested in 135 teams.
We tested the possibility that learning trajectories may follow a quadratic trend, but results were non-significant. Finally, we assessed models in which intercepts and slopes were allowed to vary across teams. Results indicated significant slope variance for both learning behaviors. That is, teams differed significantly from each other on their trajectories of exploratory and exploitative learning over time. The time factor (i.e., slope variance) accounted for 12.30% and 17.94% of the within-team exploratory and exploitative learning variance, respectively.

We expected that innovation ratings would predict slope variance in exploratory learning, and suggested LGO would predict intercept and slope variance in exploratory learning. RCM analyses were conducted in which initial learning and learning change were treated as level-1 outcomes, and innovation and GO were treated as level-2 predictors of learning intercept and slope (Table 3). Innovation did not predict slope variance in exploratory learning ($t = -.039$, ns). However, LGO predicted the intercept of team exploratory learning ($t = 4.38$, $p < .001$), suggesting that teams higher on LGO have greater initial levels of exploratory behaviors. Additionally, LGO showed a marginally significant interaction with time, meaning teams higher on LGO showed a flatter exploratory learning slope ($t = -1.77, p = .078$). In other words these teams maintained higher levels of exploratory behavior across time (see Figure 4).

Table 3
Model Estimates of Predictors of Exploratory and Exploitative Learning

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>SE</th>
<th>df</th>
<th>t</th>
<th>p</th>
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<td>Final Level 2 model - Explore</td>
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<tr>
<td>Intercept</td>
<td>-23.38</td>
<td>20.64</td>
<td>258</td>
<td>-1.13</td>
<td>.258</td>
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<tr>
<td>Time</td>
<td>27.88</td>
<td>12.26</td>
<td>258</td>
<td>2.27</td>
<td>.024</td>
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<tr>
<td>Team Innovation</td>
<td>-0.34</td>
<td>1.56</td>
<td>129</td>
<td>-0.22</td>
<td>.830</td>
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<tr>
<td>Learning Goal Orientation</td>
<td>21.67</td>
<td>4.95</td>
<td>129</td>
<td>4.38</td>
<td>.000</td>
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<tr>
<td>Team Innovation × Time</td>
<td>-0.36</td>
<td>0.92</td>
<td>258</td>
<td>-0.39</td>
<td>.700</td>
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<tr>
<td>Learning Goal Orientation × Time</td>
<td>-5.12</td>
<td>2.94</td>
<td>258</td>
<td>-1.77</td>
<td>.078</td>
</tr>
<tr>
<td>Final Level 2 model - Exploit</td>
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<tr>
<td>Intercept</td>
<td>35.19</td>
<td>16.36</td>
<td>259</td>
<td>2.15</td>
<td>.032</td>
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<tr>
<td>Time</td>
<td>4.44</td>
<td>9.73</td>
<td>259</td>
<td>0.46</td>
<td>.648</td>
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<td>Team Innovation</td>
<td>1.80</td>
<td>1.55</td>
<td>129</td>
<td>1.16</td>
<td>.249</td>
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<td>Performance Goal Orientation</td>
<td>7.97</td>
<td>4.18</td>
<td>129</td>
<td>1.91</td>
<td>.059</td>
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<tr>
<td>Team Innovation × Time</td>
<td>-1.17</td>
<td>0.92</td>
<td>259</td>
<td>-1.26</td>
<td>.208</td>
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<tr>
<td>Performance Goal Orientation × Time</td>
<td>0.54</td>
<td>2.49</td>
<td>259</td>
<td>-0.22</td>
<td>.830</td>
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</table>

Note: n = 405 observations nested in 135 teams
Regarding exploitative learning, we expected innovation ratings would predict slope variance in exploitative learning, and suggested PGO would predict the intercept and slope of exploitative learning. As seen in Table 3, team innovation did not significantly predict slope variance in exploitative learning ($t = 1.16, p = .249$). However, PGO was a marginally significant predictor of the exploitative learning intercept, suggesting that teams higher on PGO have greater initial levels of exploitative behaviors ($t = 1.91, p = .059$). Unlike LGO, PGO did not predict the slope of exploitative behavior; however, as seen in Table 1, PGO did correlate with Time 1 and Time 3 exploitative behavior ($r = .22; .23$, respectively).

**Discussion**
This study investigated the temporal nature of team learning behaviors in a first-year Engineering Design and Communications course. The pattern that emerged suggested that both team learning behaviors increase over time. Perhaps, in a team setting, these behaviors cycle in a reciprocal pattern for sub-tasks within a broader project. Indeed, the reoccurring phase model proposes that teams are multitasking units engaging in multiple processes simultaneously and sequentially. Combined with temporal pressures of an approaching deadline, the observed positive learning trends may be due to smaller reciprocal processes of exploratory and exploitative activities occurring within a broader deliverable.

No relationship was found between learning and innovation, which is surprising given the theoretical and empirical evidence that points to a positive relationship. One explanation is that learning actions require time to be encoded. Receiving feedback helps teams encode and adopt learning actions that lead to successful components of future performance. Therefore, teams apply proven patterns of interaction when similar conditions arise. Thus learning behaviors may only predict outcomes in subsequent performance cycles. A methodological
explanation for the findings may be unreliability in innovation ratings. Innovation ratings were collected from 23 TAs and because each TA rated only the teams in their individual lab section, I was unable to calculate inter-rater reliability and agreement. Thus, it is possible that innovation is a difficult construct to calibrate raters on, and a lack of agreement may have masked true relationships between learning and innovation. Another possible explanation may be related to the grading rubric used for the project. Specifically, for teams to receive a high grade on the project, they did not necessarily have to create a novel solution, as teams were scored based on whether or not their device met specific requirements and was able to successfully transfer the rock. For these reasons, the relationship between team learning and innovation may have been masked, and may be stronger in design projects that allow member to have more autonomy.

An important contribution of this research involves the role of GO. Teams with weak LGOs engaged in less exploratory behaviors at the start of the project; however, as the deadline approached, these teams increased exploratory behaviors. In contrast, strong LGO teams maintained high levels of exploratory behavior over time. Temporal motivation theory emphasizes time as a critical motivational force, where the perceived utility of action increases as deadlines approach. Drawing on this theory, it is plausible that the effect of temporal pressure on exploratory behavior is stronger in teams with lower LGOs. More specifically, these teams may be driven to “play catch up” due to time related pressures, whereas teams with strong LGOs may be more intrinsically motivated to engage in high levels of exploratory behavior and to maintain these actions over time.

Findings involving PGO indicated that high-PGO teams engaged in more exploitative actions, such as building on existing certainties, during the first week of the project. Interestingly, PGO was not related to exploratory learning at any time point, but LGO was related to both exploratory and exploitative learning at almost every time point. Taken together, team GO appears to be an influential factor in determining how teams pursue different learning activities. One limitation of this research is the single-level conceptualization of team learning. More specifically, this study did not consider the complex interplay of individual members’ knowledge and actions that likely contribute to the emergence of learning as a group-level phenomenon. Future research should take a multilevel perspective and consider how individual members’ learning plays into group-level learning phenomena. Although, it is still unclear as to whether exploratory and exploitative learning behaviors have differential implications for team outcomes based on when they occur, it may be important to encourage students to engage in both learning behaviors.

**Conclusion**

To our knowledge, this is the first study to model team-level exploratory and exploitative learning longitudinally, and to examine predictors of these learning behaviors in teams. Due to the widespread use of project teams in engineering education, an understanding of team learning processes is critical. The implications of the study findings are three-fold. First, our research highlights the importance of considering team composition variables when grouping students into project teams. More specifically, we need to further examine and consider how individual students’ preferences, traits, and tendencies can act as driving factors of team behavior. Second, this study calls attention to the temporal nature of exploratory and exploitative learning behavior. Instructors should be mindful of such patterns and encourage teams to adopt different learning behavior.
activities to match the temporal rhythms of the project work. Third, future research is needed to examine the implication of these learning activities on outcomes other than innovation (e.g., individual learning, project grades, team potency). Although innovation ratings were unrelated to learning behaviors in the current study, we feel this was primarily due to difficulty in assessing innovation. Future research should examine how team exploratory and exploitative behavior is related to more robust and stable outcome measures.

1. S. W. Kozlowski and B. S. Bell, “Team learning, development, and adaptation.” Group learning, 2008, pp. 5-44.
Appendix A
Relative Percentile Method Rating Form for Team Exploratory and Exploitative Behaviors

Directions:
You will be asked to report on the degree to which your team engaged in exploratory and exploitative learning over the past week, up to and including today’s lab. Please take a minute to discuss the answer as a team, and reflect back on how much your group engaged in these behaviors over the past week.

Next, place a mark on the line best representing your teams answer, and label the line with today’s date. Please note that there is no correct or best answer, and teams will likely display a wide range of these behaviors at various points in the project. Most important, the midpoint marked 50 does not mean 50% or half but, instead, signifies the average amount of the behavior has occurred in the team in comparison to all other teams. When making future ratings you will compare each week’s rating to your previous week’s ratings.

Exploratory Behaviour
Exploration, in the current context, involves experimentation, flexibility in thinking, searching for new information, seeking variation, testing novel ideas and concepts, and discovering new information. Often these behaviors create new capabilities and the acquisition of new knowledge.

Please rate the extent to which your team engaged in these exploratory behaviours over the past week, up to and including today’s lab. Place a vertical dash on the line that best represents your team’s answer and label it with today’s date.

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<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>Week 1</td>
<td>Week 2</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>50</td>
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<tr>
<td></td>
<td>Below Average</td>
<td>Average</td>
</tr>
</tbody>
</table>

Exploitative Behaviour
Exploitation, in the current context, involves refining existing knowledge and skills, executing task work, working toward efficiency, practicing existing skills, production, implementation of ideas, and utilizing standard knowledge. Often these behaviours lead to enhanced efficiency and reinforce existing capabilities.

Please rate the extent to which your team engaged in these exploratory behaviours over the past week, up to and including today’s lab. Place a vertical dash on the line that best represents your team’s answer and label it with today’s date.

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<thead>
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<td></td>
<td>0</td>
<td>50</td>
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<tr>
<td></td>
<td>Below Average</td>
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Appendix B
Innovation Rating Training Materials

Definition of Innovation

Innovation encompasses two components:

1. The existence of a novel, unique, or original idea(s).
2. The effective implementation of the idea(s) or functionality of the prototype.

Scale Directions

- In principal, if all the teams could be measured by one rater, each team could be ranked from most effective to least effective.
- A team project of average innovativeness would be ranked in the middle of the scale.
- If you rank a team at the 50 mark this indicated that half of all the other projects would be more innovative than the team and the other half of all team projects would be less innovative than the team.
- You are being asked to make a relative judgment about where the teams in your lab fall on the scale relative to all the teams in ENGG 200.
- On the next page you will fill in the information about each team. When you place a vertical dash on the scale label it with the team number assigned to each team.
- **Important:** When making your ratings of how innovative each team was you must consider both aspects of innovation: existence of novel and original ideas and the effective implementation of the idea or functionality of the project.

EXAMPLE

<table>
<thead>
<tr>
<th>Team B</th>
<th>Team A</th>
<th>Team C</th>
<th>Team D</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Below Average</td>
<td>Average</td>
<td>Above Average</td>
</tr>
</tbody>
</table>

In principal, if all the teams could be measured by one rater, each team could be ranked from most effective to least effective.

A team project of average innovativeness would be ranked in the middle of the scale.

If you rank a team at the 50 mark this indicated that half of all the other projects would be more innovative than the team and the other half of all team projects would be less innovative than the team.

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